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(54) **METHOD AND APPARATUS FOR PROVIDING HAPTIC FEEDBACK UTILIZING MULTI-ACTUATED WAVEFORM PHASING**

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(52) **U.S. Cl.**
USPC **345/173**; 340/407.1; 345/156

(58) **Field of Classification Search**
USPC 345/156–184; 178/18.03–18.11; 340/407.1, 407.2
See application file for complete search history.

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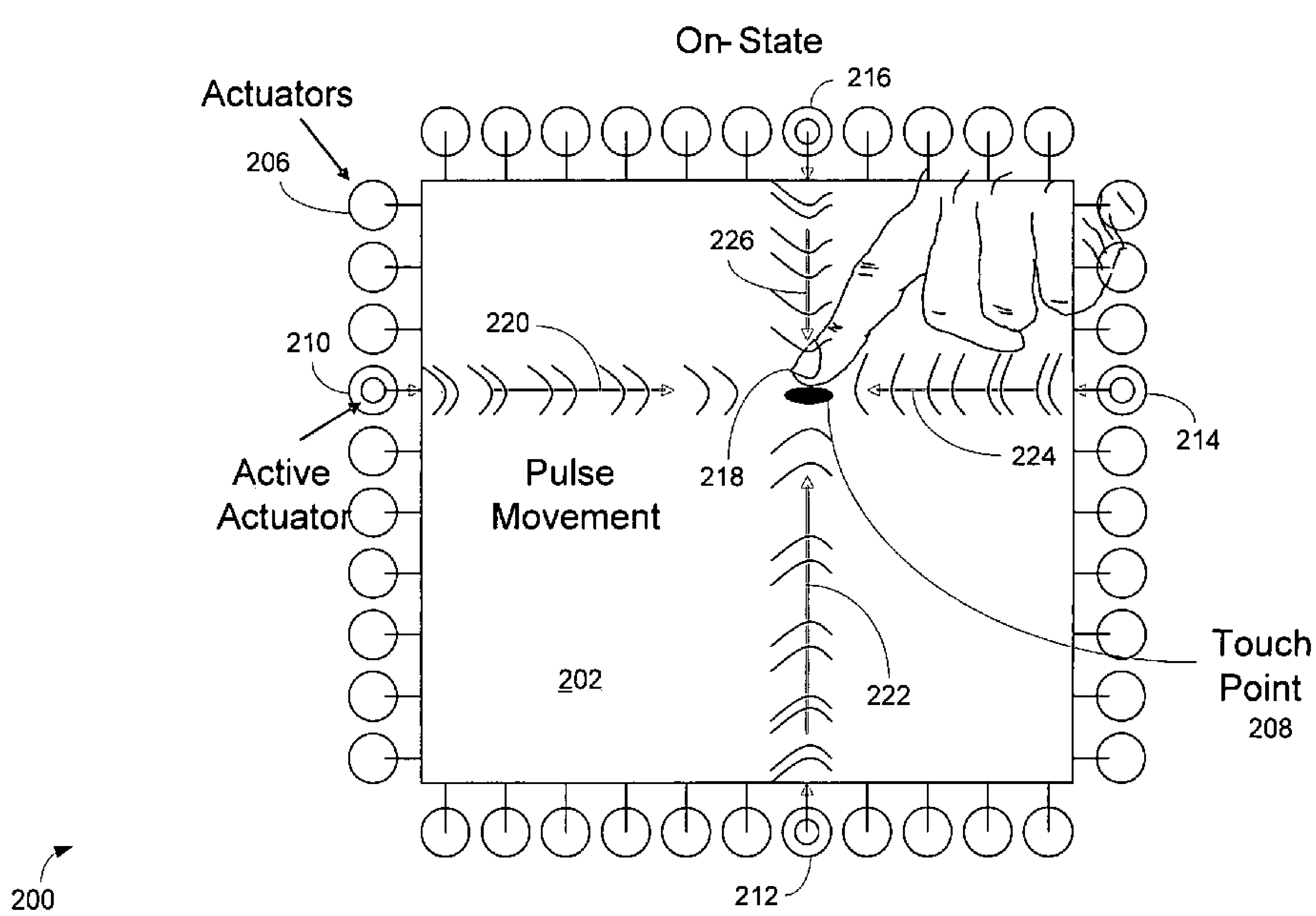
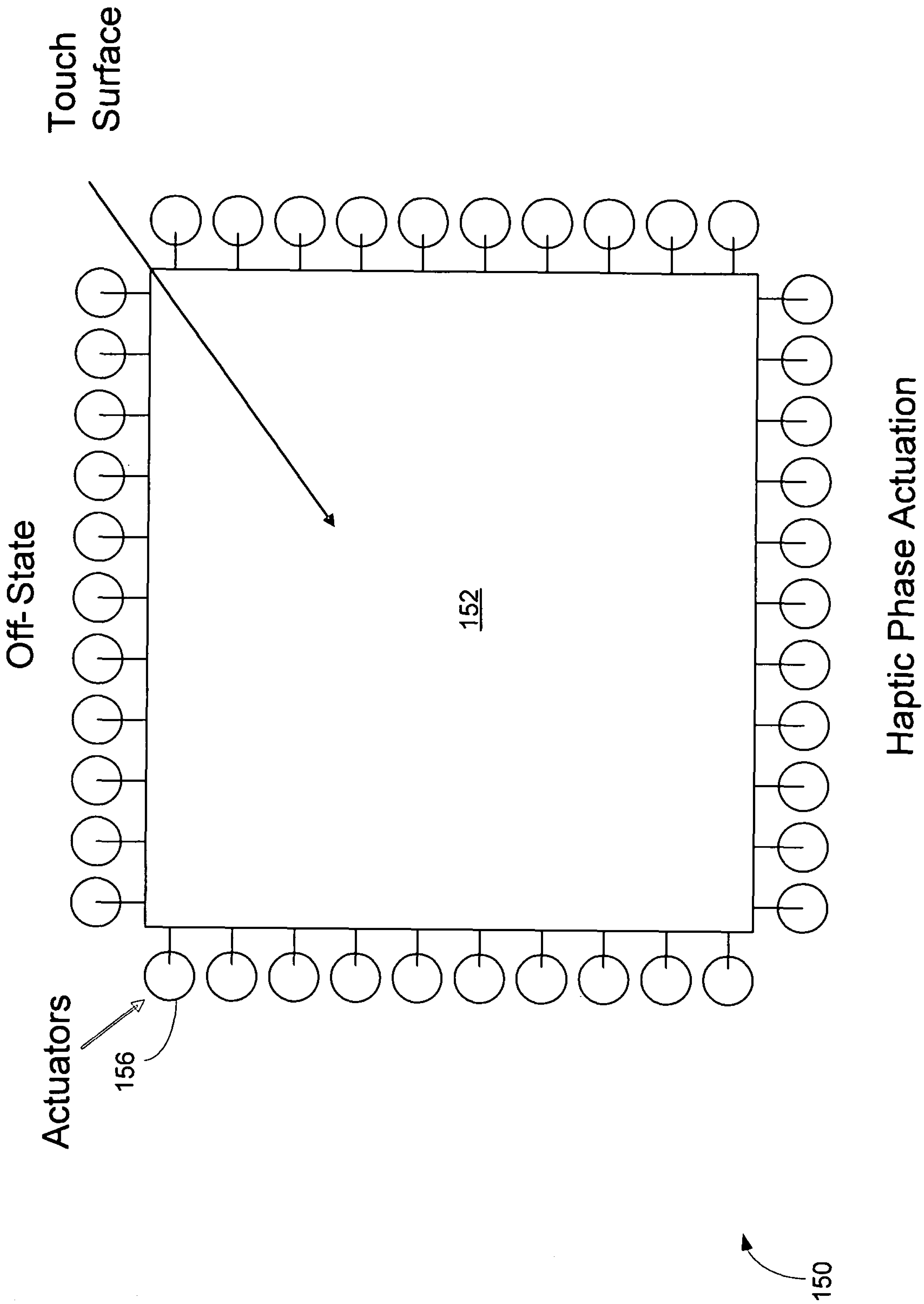
(57) **ABSTRACT**

A method and device for generating haptic feedback over a touch surface using multi-actuated waveform phasing are disclosed. A haptic device, in one embodiment, includes a touch surface and a group of haptic actuators. The touch surface is capable of sensing an event, wherein the event can be a contact on the touch surface or a movement nearby the surface. A portion of the haptic actuators, which are coupled to the touch surface, is configured to provide haptic feedback on the touch surface in response to the event. Another portion of the haptic actuators is used to minimize unwanted haptic effect on the touch surface.

22 Claims, 13 Drawing Sheets





Touch Surface
Off-State
152
Haptic Phase Actuation
Actuators
156
150

FIG 1(a)

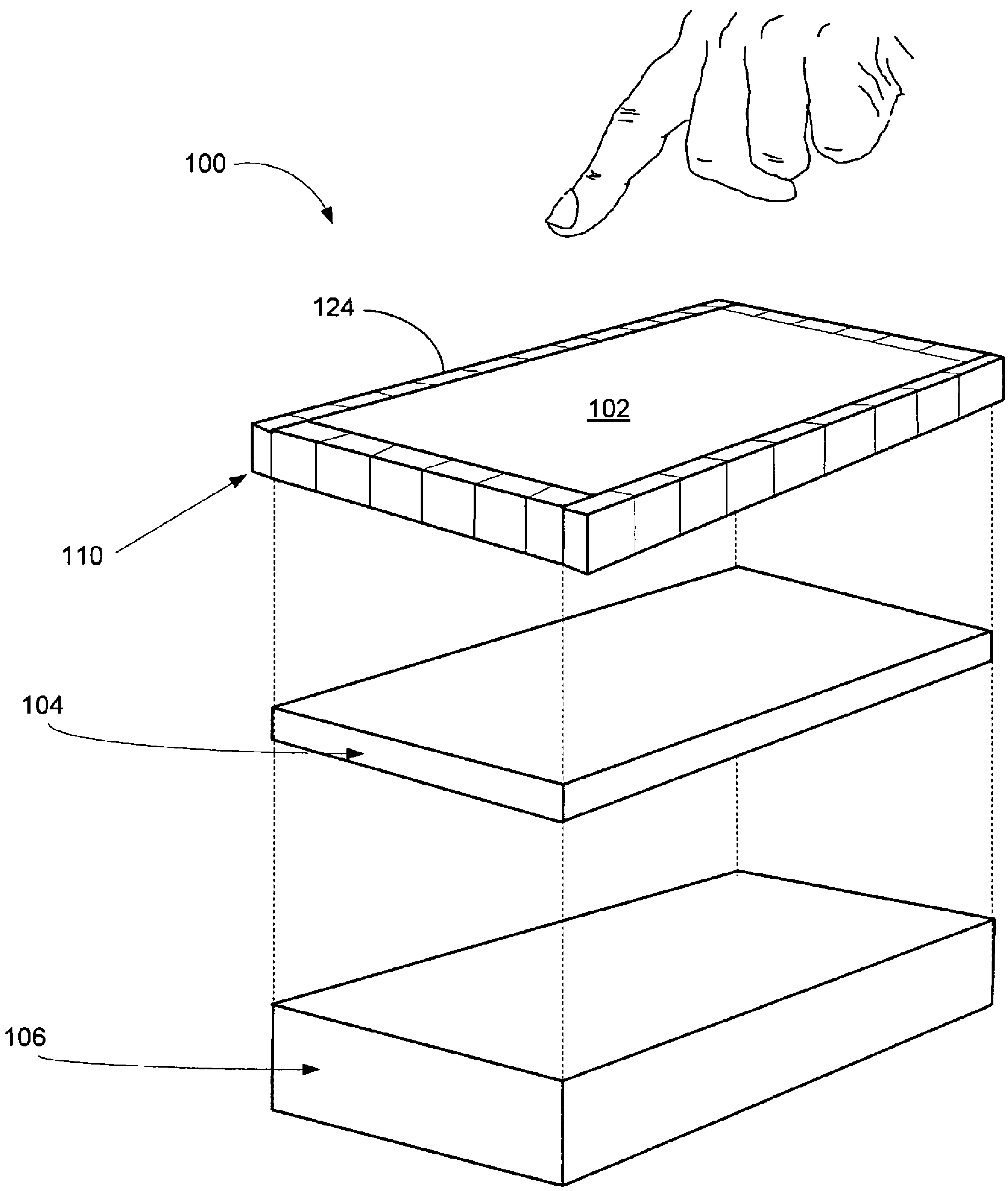


FIG 1(b)

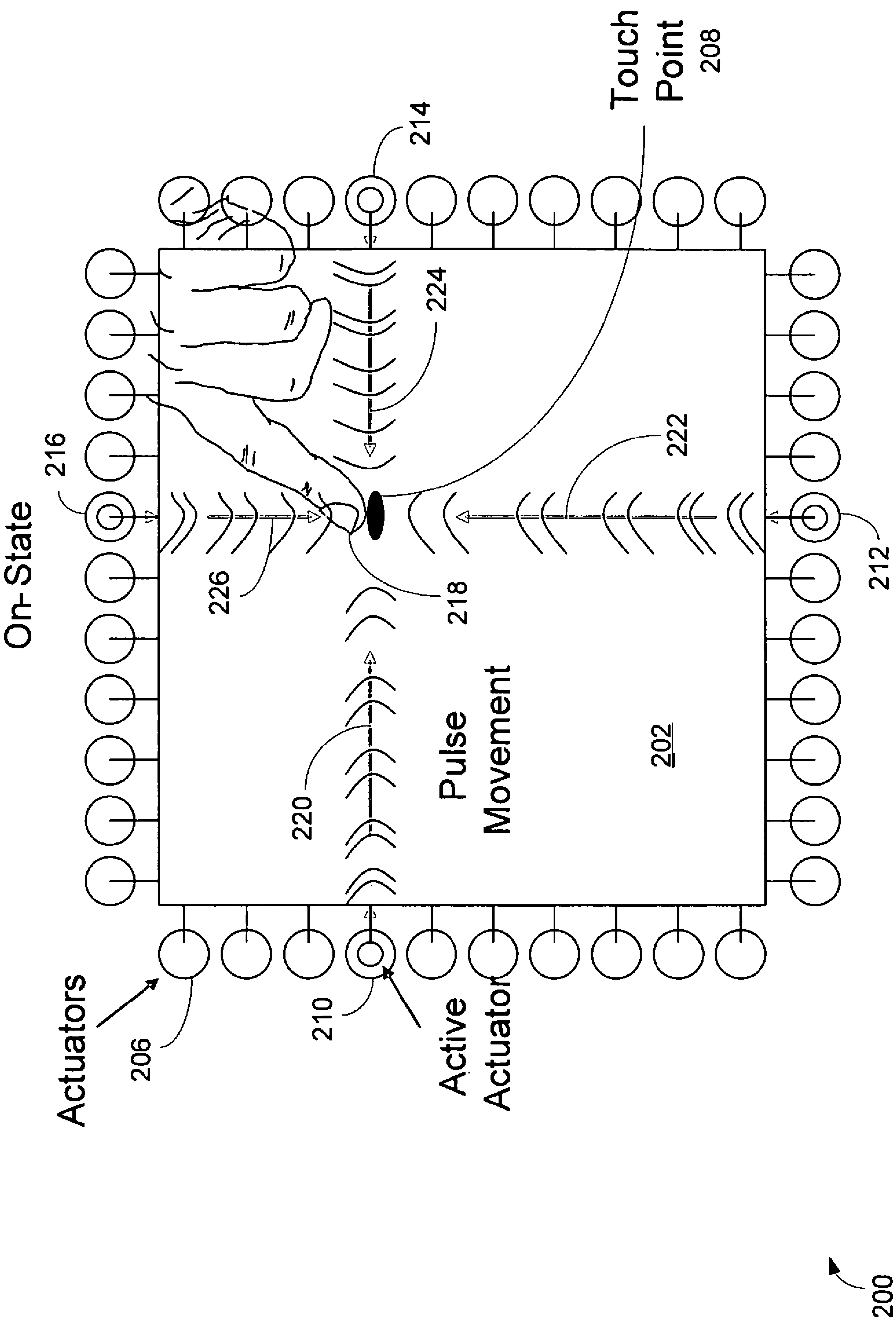

On-State
216
214
Touch
Point
208
224
222
226
218
212
220
Pulse
Movement
202
Actuators
206
210
Active
Actuator
200

FIG 2(a)

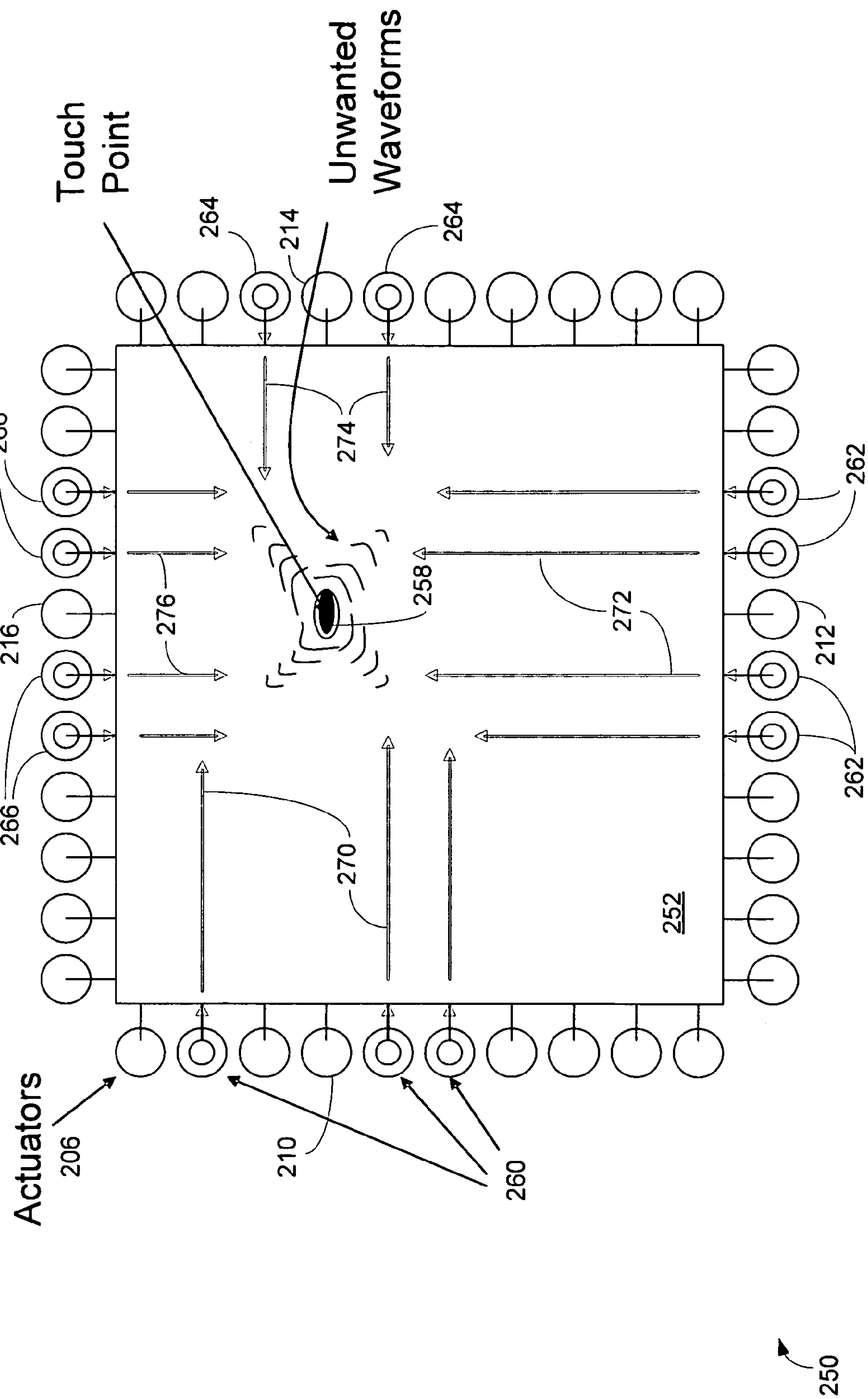

Touch Point
Unwanted Waveforms
264
214
264
266
274
262
258
276
272
216
212
266
270
262
252
Actuators
206
210
260
250

FIG 2(b)

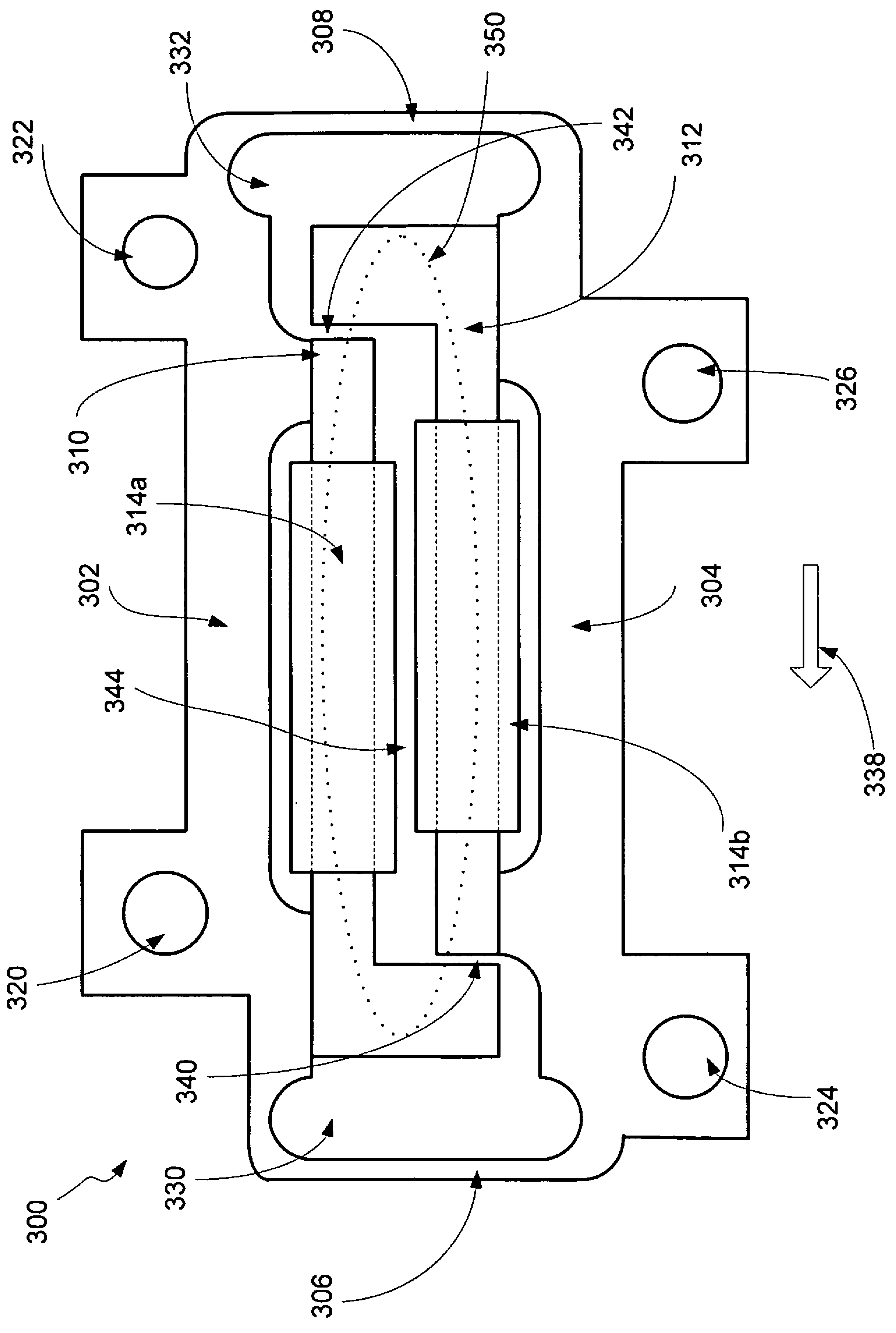

300
302
304
306
308
310
312
314a
314b
320
322
324
326
330
332
338
340
342
344
350

FIG 3

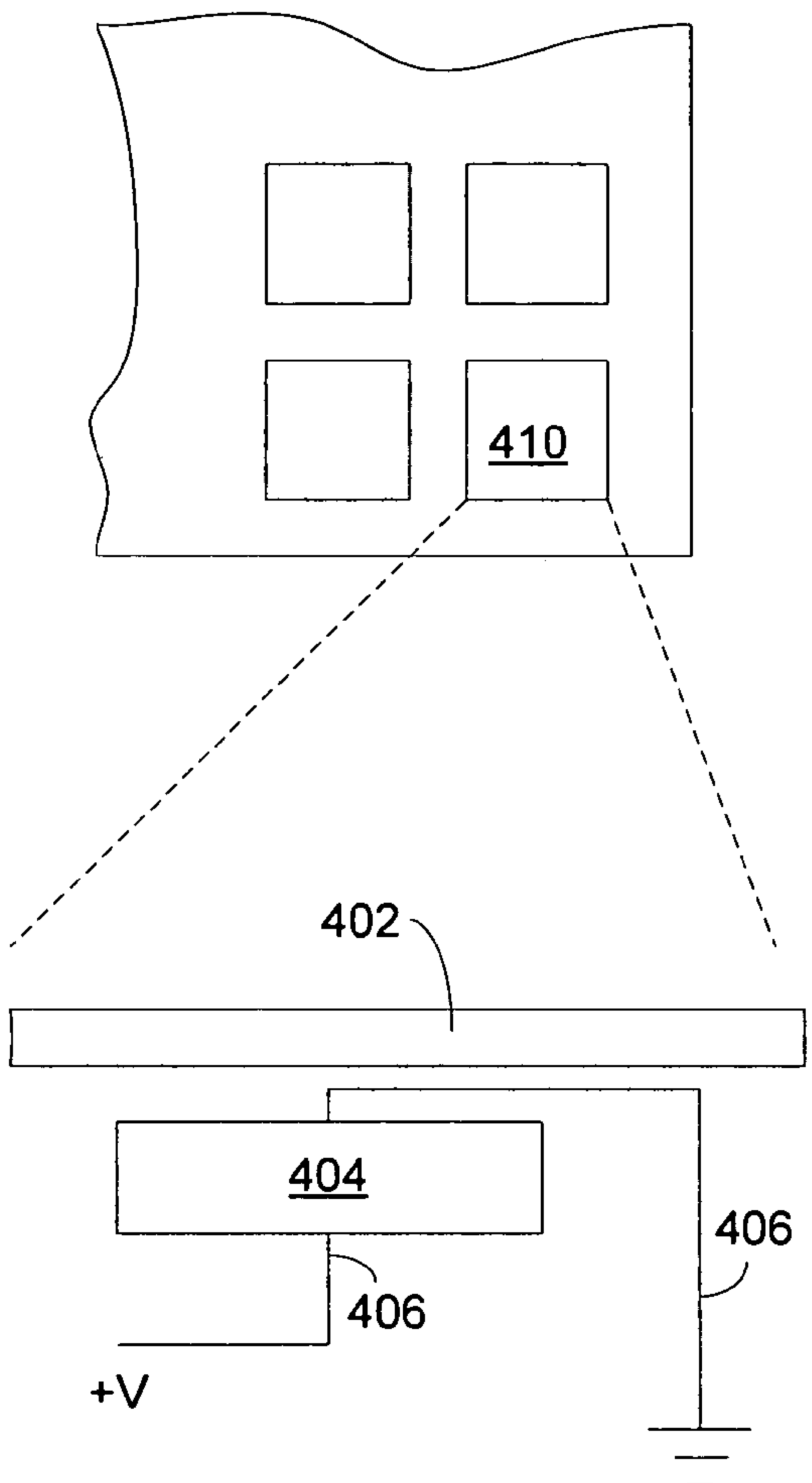


FIG 4(a)

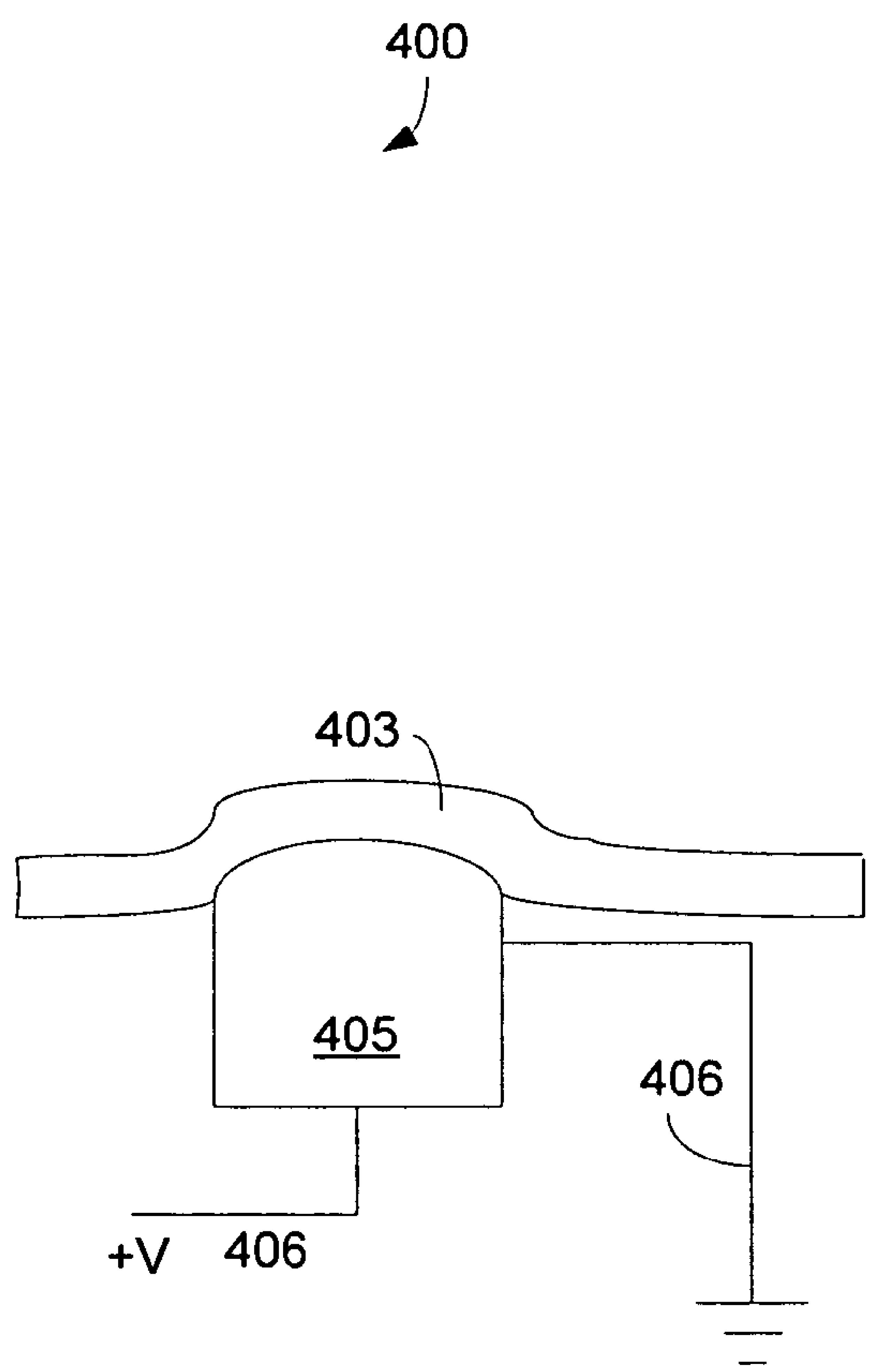


FIG 4(b)

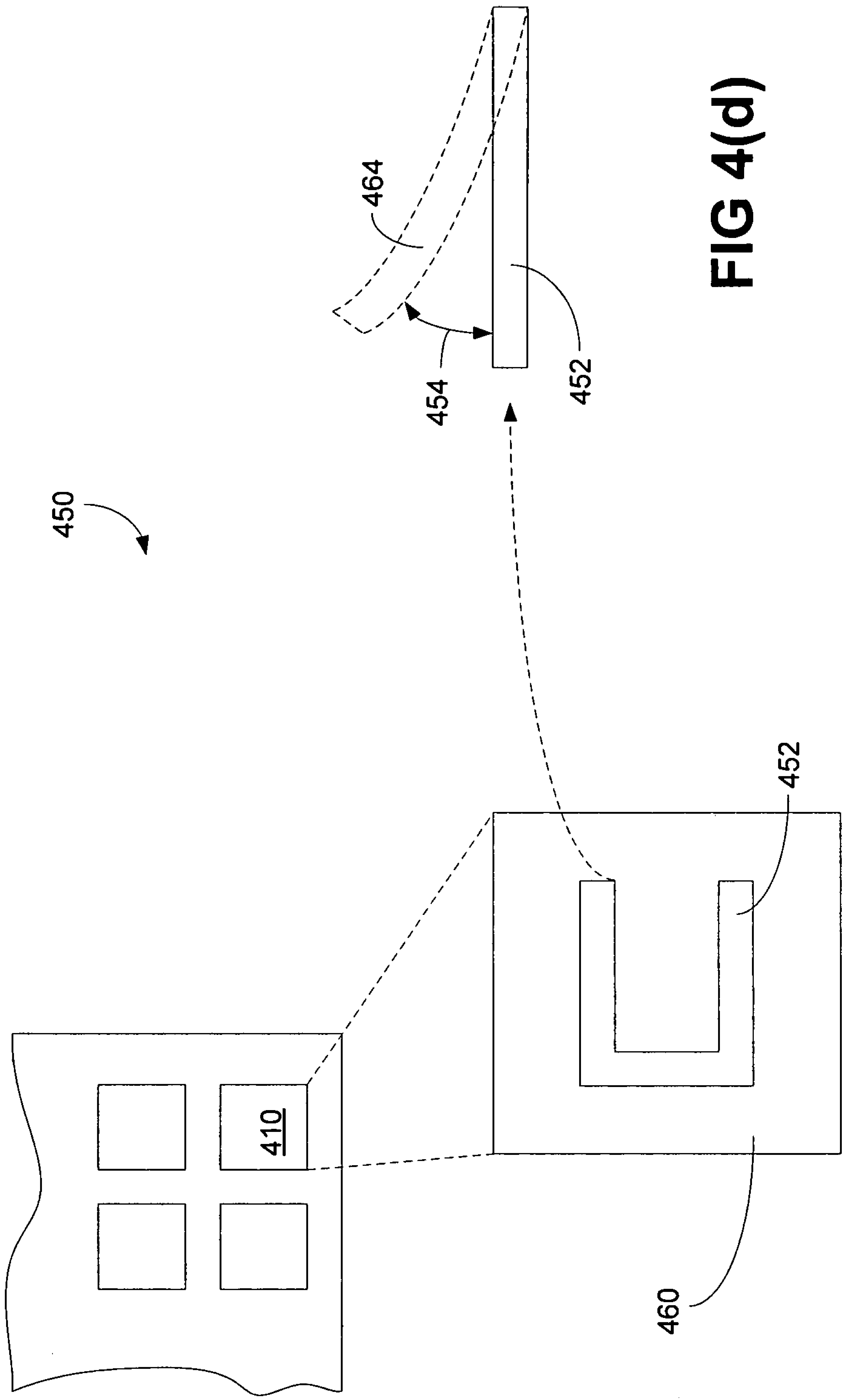


FIG 4(d)

FIG 4(c)

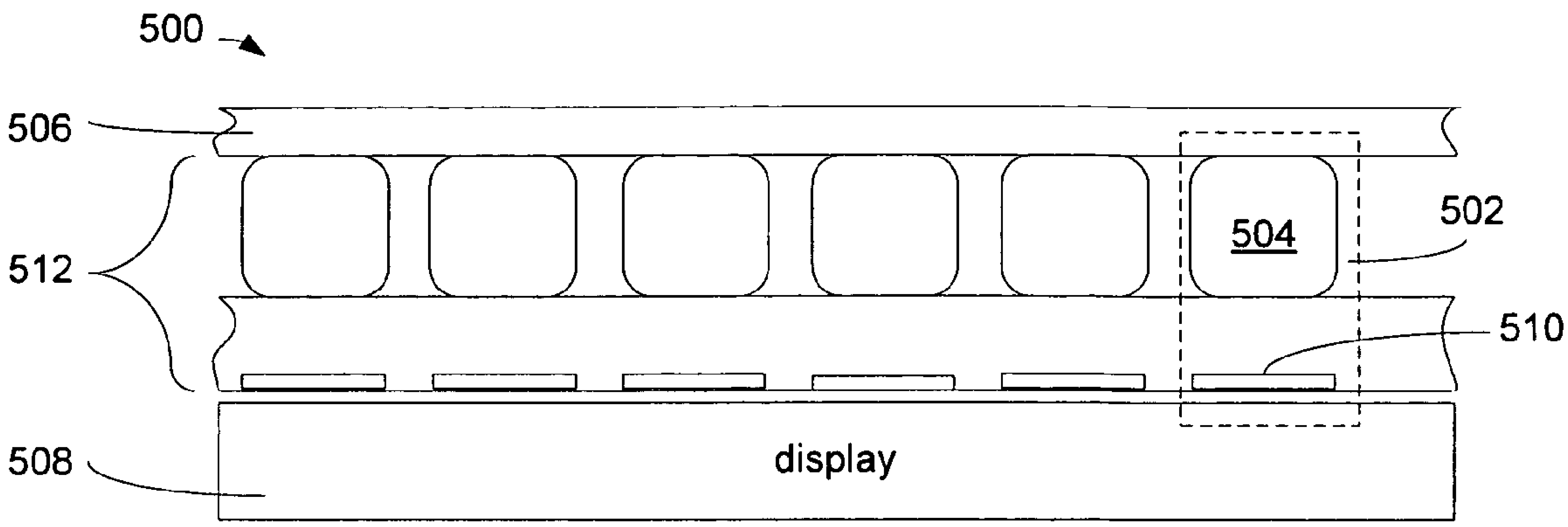

500
506
512
504
502
510
508
display

FIG 5(a)

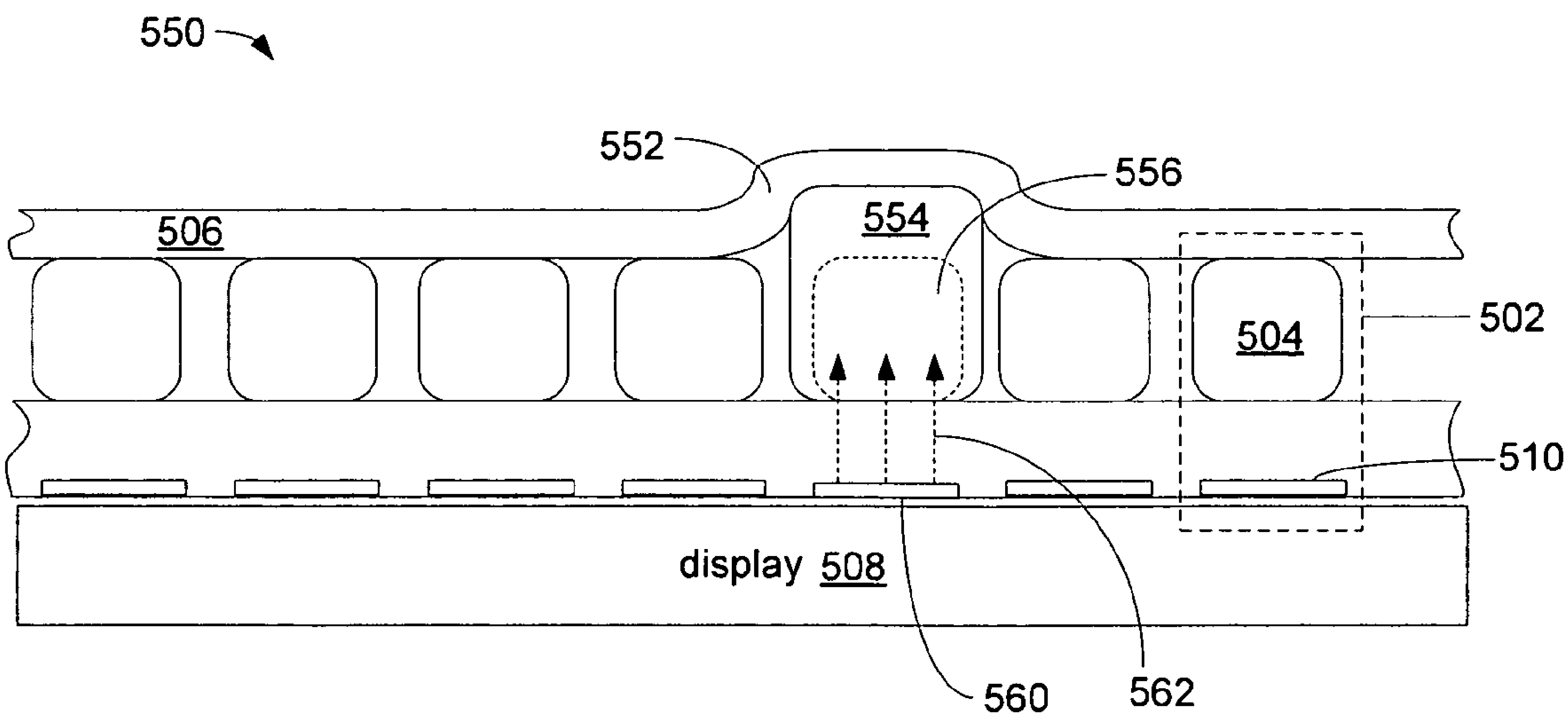

550
552
556
554
506
504
502
510
display 508
560
562

FIG 5(b)

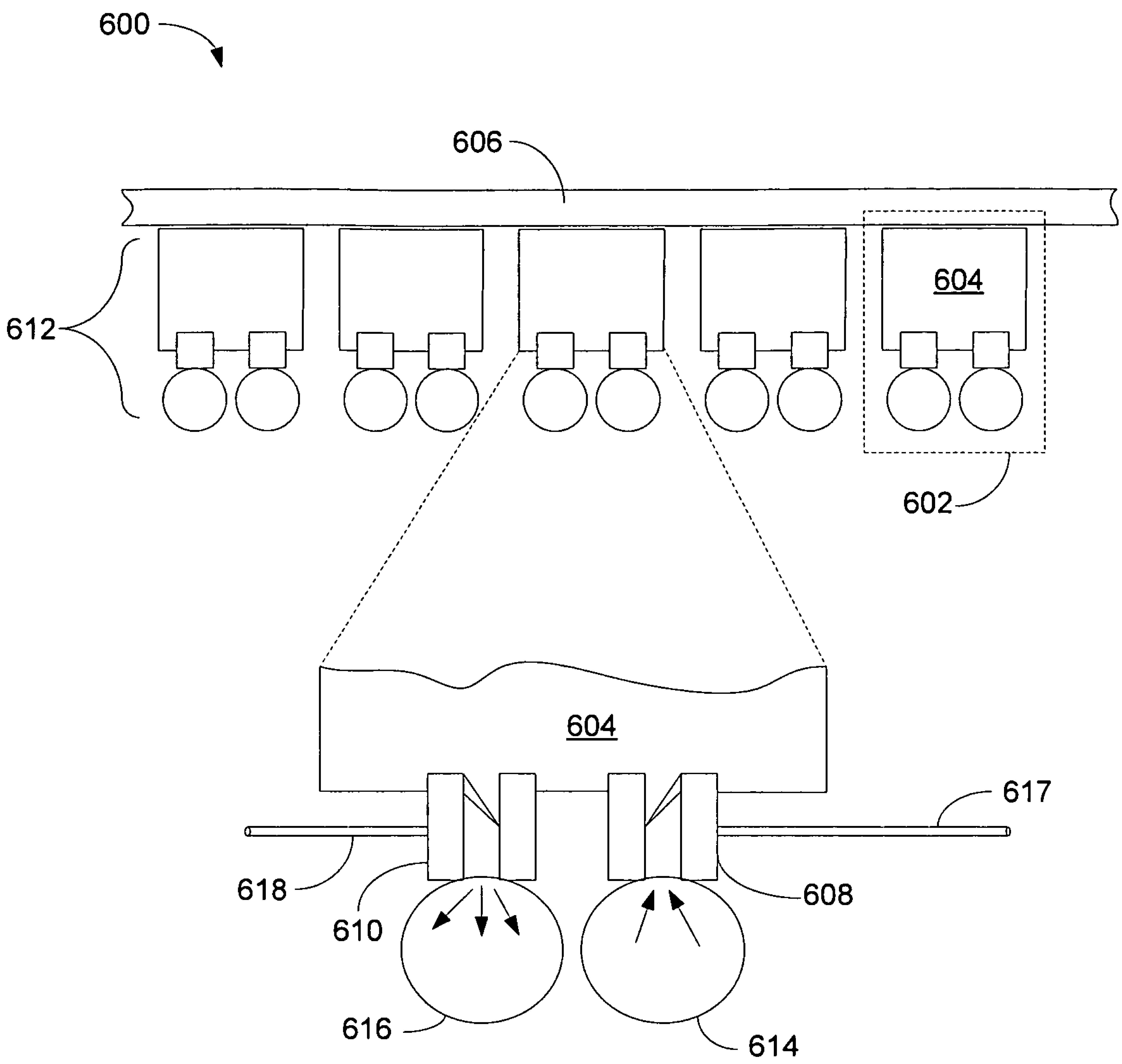


FIG 6 (a)

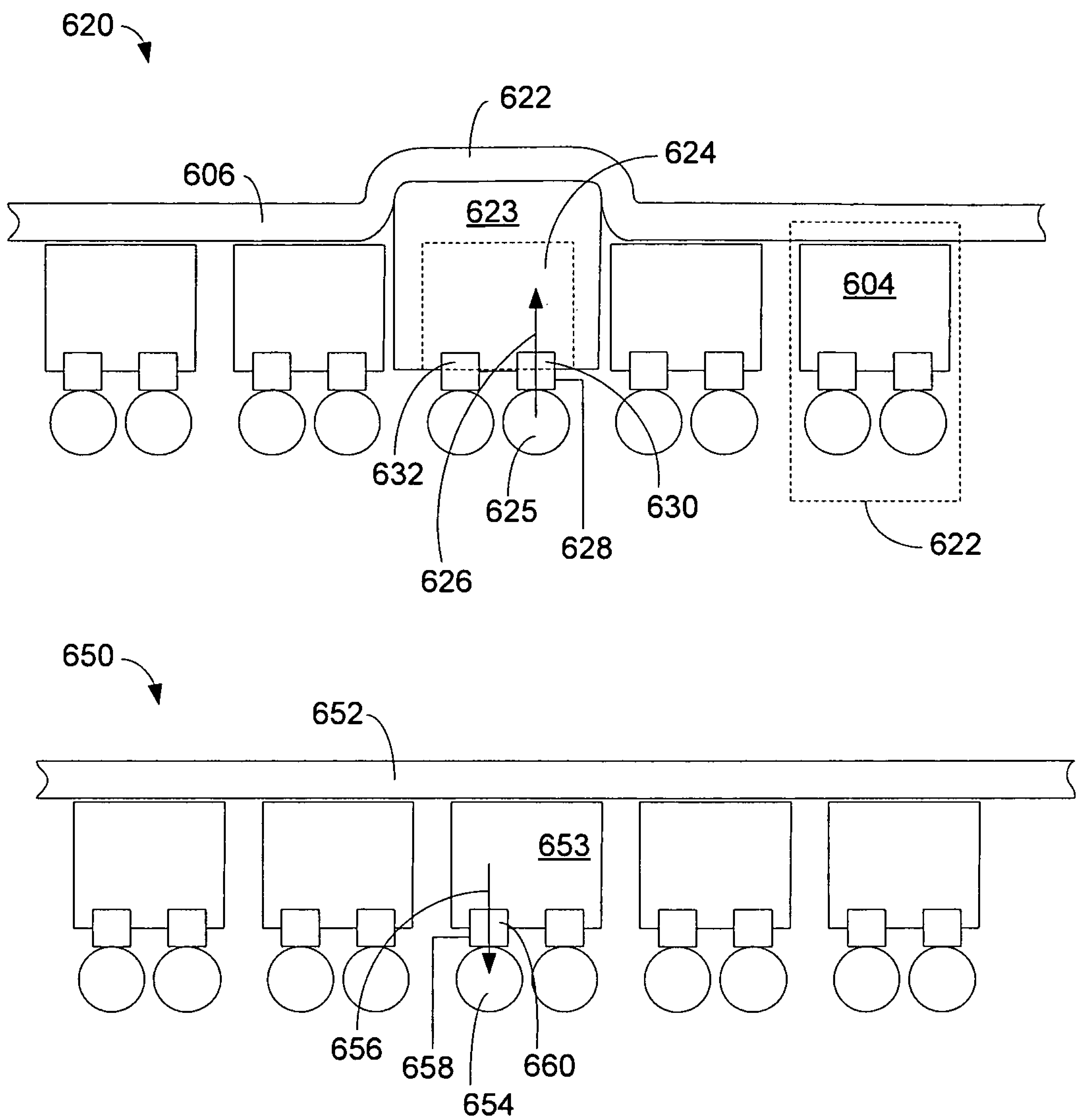

620
622
606
624
623
604
632
625
630
628
626
622
650
652
653
656
658
660
654

FIG 6(b)

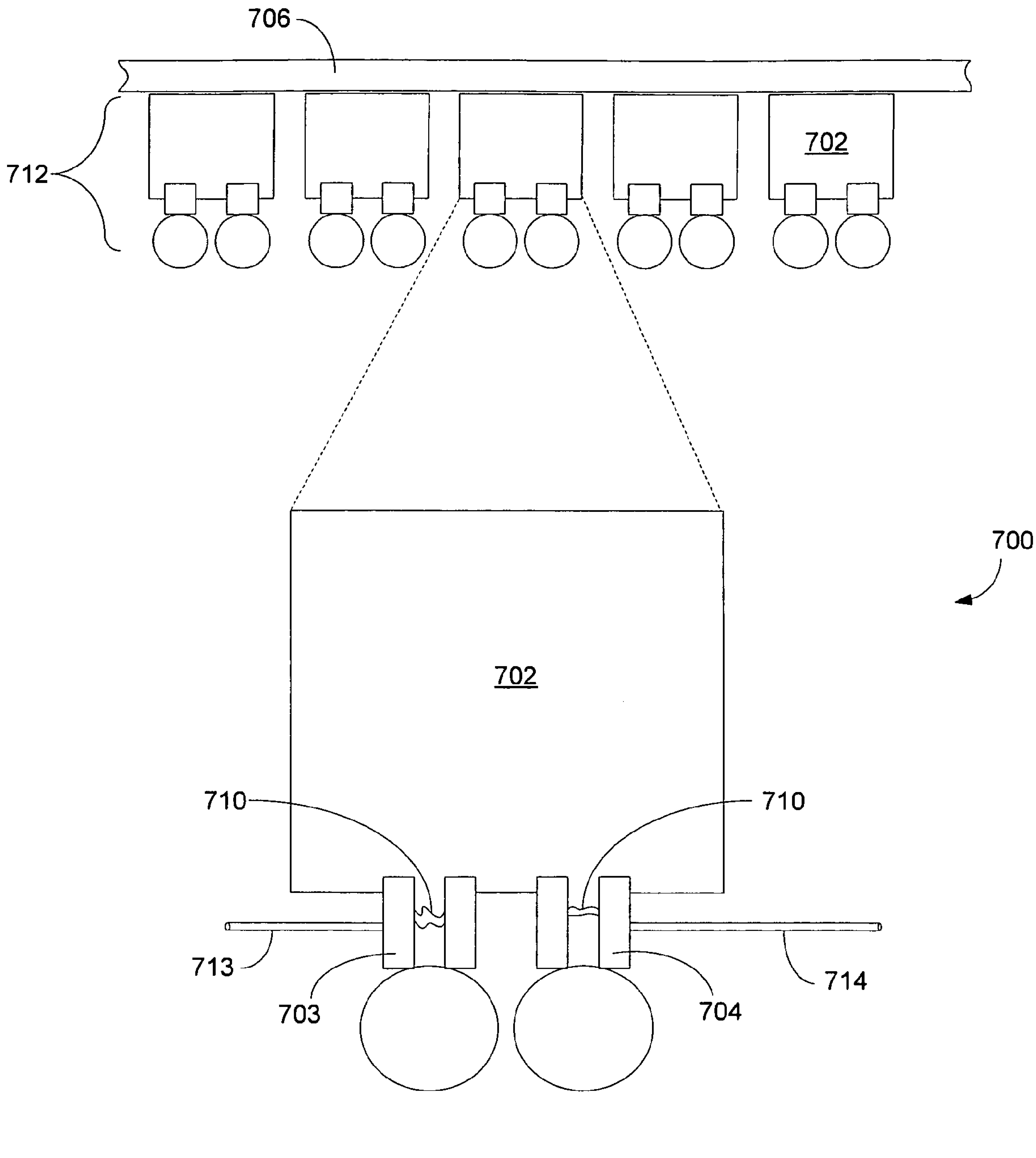


FIG 7

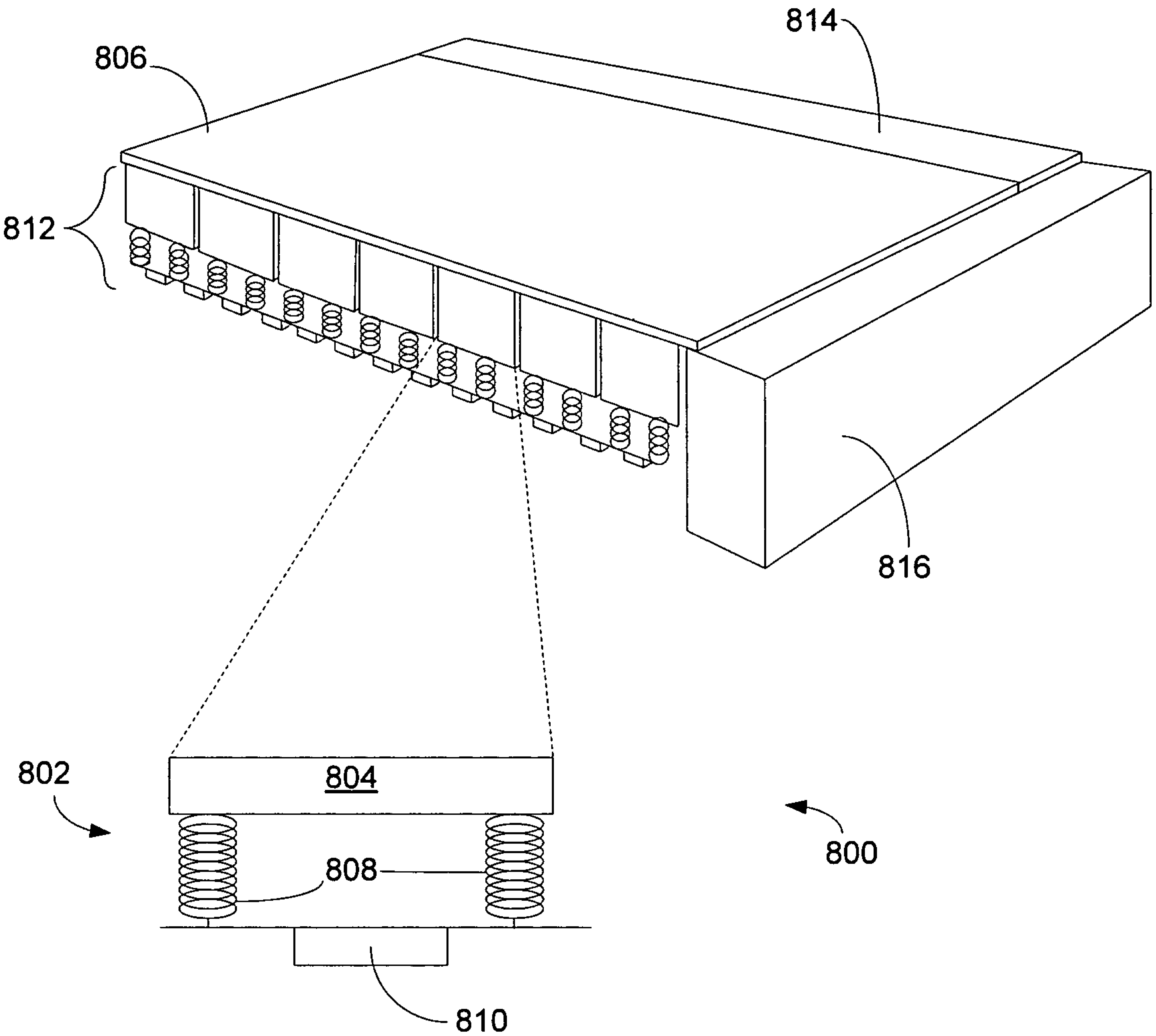


FIG 8

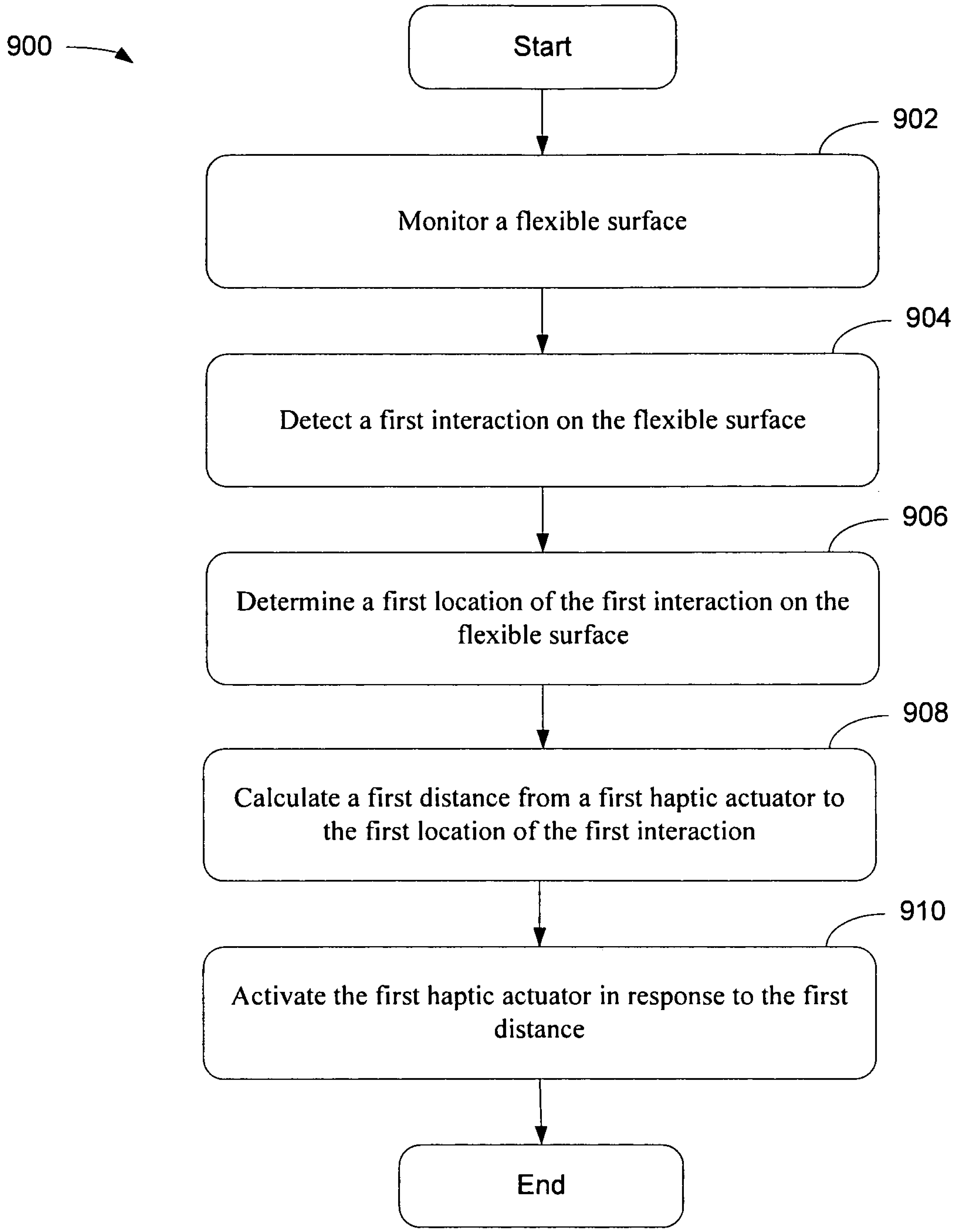

900
Start
902
Monitor a flexible surface
904
Detect a first interaction on the flexible surface
906
Determine a first location of the first interaction on the flexible surface
908
Calculate a first distance from a first haptic actuator to the first location of the first interaction
910
Activate the first haptic actuator in response to the first distance
End

FIG 9

METHOD AND APPARATUS FOR PROVIDING HAPTIC FEEDBACK UTILIZING MULTI-ACTUATED WAVEFORM PHASING

RELATED APPLICATIONS

This application is related to the following co-pending applications, each assigned to the Assignee of the present invention.

a. application Ser. No. 11/823,192, filed Jun. 26, 2007, entitled "Method and Apparatus for Multi-touch Tactile Touch Panel Actuator Mechanisms";

b. application Ser. No. 11/823,258, filed Jun. 26, 2007, entitled "Method and Apparatus for Multi-touch Haptic Touch Panel Actuator Mechanisms"; and

c. application Ser. No. 11/943,862, filed Nov. 21, 2007, entitled "Method and Apparatus for Providing a Fixed Relief Touch Screen with Locating Features Using Deformable Haptic Surfaces."

d. application Ser. No. 12/061,463, filed Apr. 2, 2008, entitled "Method and Apparatus for Providing Multi-Point Feedback Texture Systems."

FIELD

The exemplary embodiment(s) of the present invention relates to a field of electronic interface devices. More specifically, the exemplary embodiment(s) of the present invention relates to generation of haptic feedback.

BACKGROUND

As computer-based systems, appliances, automated teller machines (ATM), point of sale terminals and the like have become more prevalent in recent years, the ease of use of the human-machine interface is becoming more important. Such interfaces should operate intuitively and require little or no user training whereby they may be employed by virtually anyone. Many conventional user interface devices are available on the market, such as key boards, mouse, joysticks, and touch screens. One of the most intuitive and interactive interface devices known is the touch panel, which can be a touch screen or a touch pad. A touch screen includes a touch sensitive input panel and a display device, and provides a user with a machine interface through a panel sensitive to the user's touch and displaying content that the user "touches." A conventional touch pad is a small planar rectangular pad, which can be installed near a display, on a computer, an automobile, ATM machines, and the like.

A conventional touch sensitive panel, for instance, usually has a smooth flat surface and uses sensors such as capacitive sensors and/or pressure sensors to sense locations being touched by a finger(s) and/or an object(s). A user, for example, presses a region or a point on a typical touch screen with a fingertip to emulate a button press and/or moves his or her finger on the panel according to the graphics displayed behind the panel on a display device.

A problem associated with a smooth flat surface touch screen is that it feels flat and smooth when a user touches the screen even though the image behind the surface shows an object such as a button. A conventional approach to compensate for flat and smooth touch feeling is to use haptic responses. To generate haptic responses that emulate an object such as a button, typical mechanical actuators or carriers, for instance, can be used to provide a virtual object or a barrier sensation.

A drawback associated with the conventional approach for generating haptic response is that it relies on global motion of a mechanical carrier attached to the touch screen. Another drawback associated is that it is often difficult to generate clear or crisp haptic responses.

SUMMARY

A haptic mechanism capable of generating haptic feedback over a touch surface using multi-actuated waveform phasing is described. The haptic device, in one embodiment, includes a touch surface and a group of haptic actuators. The touch surface is capable of sensing an event, wherein the event can be a contact on the touch surface or a movement nearby the touch surface. A portion of the haptic actuators, which are coupled to the touch surface, is configured to provide haptic feedback on the touch surface in response to the event. Another portion of the haptic actuators is used to minimize unwanted haptic responses on the touch surface.

Additional features and benefits of the exemplary embodiment(s) of the present invention will become apparent from the detailed description, figures and claims set forth below.

BRIEF DESCRIPTION OF THE DRAWINGS

The exemplary embodiment(s) of the present invention will be understood more fully from the detailed description given below and from the accompanying drawings of various embodiments of the invention, which, however, should not be taken to limit the invention to the specific embodiments, but are for explanation and understanding only.

FIGS. **1**(*a-b*) illustrate haptic devices capable of generating haptic feedback using multi-actuated waveform phasing in accordance with one embodiment of the present invention;

FIGS. **2**(*a-b*) illustrate haptic devices capable of generating haptic feedback using multi-actuated waveform phasing across a touch surface in accordance with one embodiment of the present invention;

FIG. **3** illustrates an actuator capable of generating crisp haptic effects using multi-actuated waveform phasing in accordance with exemplary embodiment(s) of the present invention;

FIGS. **4**(*a-d*) illustrate examples of haptic cells in a haptic device employing piezoelectric materials and Micro-Electro-Mechanical Systems ("MEMS") elements in accordance with one embodiment of the present invention;

FIG. **5**(*a-b*) illustrates a side view of a haptic device having an array of haptic cells with thermal fluid pockets in accordance with one embodiment of the present invention;

FIG. **6**(*a-b*) illustrates a haptic cell employing Micro-Electro-Mechanical Systems pumps to generate haptic effects in accordance with one embodiment of the present invention;

FIG. **7** illustrates a side view diagram for a haptic device having an array of haptic cells using variable porosity membrane in accordance with one embodiment of the present invention;

FIG. **8** is a side view of a haptic device having an array of haptic cells using various resonant devices in accordance with one embodiment of the present invention; and

FIG. **9** is a flowchart illustrating a process of generating haptic feedback using multi-actuated waveform phasing in accordance with one embodiment of the present invention.

DETAILED DESCRIPTION

Exemplary embodiments of the present invention are described herein in the context of a method, system and apparatus for providing haptic feedback from multi-actuated waveform phasing using perimeter actuators.

Those of ordinary skills in the art will realize that the following detailed description of the exemplary embodiment (s) is illustrative only and is not intended to be in any way limiting. Other embodiments will readily suggest themselves to such skilled persons having the benefit of this disclosure. Reference will now be made in detail to implementations of the exemplary embodiment(s) as illustrated in the accompanying drawings. The same reference indicators will be used throughout the drawings and the following detailed description to refer to the same or like parts.

In the interest of clarity, not all of the routine features of the implementations described herein are shown and described. It will, of course, be appreciated that in the development of any such actual implementation, numerous implementation-specific decisions must be made in order to achieve the developer's specific goals, such as compliance with application- and business-related constraints, and that these specific goals will vary from one implementation to another and from one developer to another.

An embodiment(s) of the present invention discloses a haptic device, which is capable of generating haptic feedback over a touch surface using multi-actuated waveform phasing. The device includes a touch surface and a group of haptic actuators, wherein the touch surface is capable of sensing an event. The event, for instance, can be a contact with the touch surface or a movement nearby the device. A portion of the haptic actuators coupled to the touch surface is used to provide haptic feedback in response to the event. Another portion of the haptic actuators is used to minimize unwanted haptic responses on the touch surface.

FIG. **1**(*a*) illustrates a haptic device **150** capable of generating haptic feedback utilizing multi-actuated waveform phasing in accordance with one embodiment of the present invention. Device **150** includes a touch surface **152** and a group of actuators **156** capable of providing haptic feedback using haptic phase actuation. Actuators **156** are coupled to the perimeter of touch surface **152**. Touch surface **152** is also known as touch pad, haptic layer, touch sensitive surface, flexible touch sensitive surface, or the like. It should also be noted that the underlying concept of the exemplary embodiment of the present invention would not change if one or more blocks (circuits or layers) were added to or removed from device **150**.

Touch surface **152**, in one aspect, includes a detecting mechanism capable of sensing an event. The event can be, but not limited to, a surface contact, a movement, an ambient condition, a sound, an optical light, and the like. The ambient condition includes surrounding temperature, light, humidity, radiation, et cetera. For instance, a surface contact has occurred when a depression on the touch surface happens via a push by a user's finger. Alternatively, a contact can be made by a pointed object, such as a stylus or a pen.

Touch surface **152**, in one embodiment, is made of flexible soft material wherein the medium of the flexible soft material is able to transmit haptic waves from a wave-generating source such as actuators **156** to wave-destination such as the contact location. For example, the touch surface **152** may be made of gel-like synthetic polymers or natural substances. The medium of gel-like polymers facilitates the travel of the haptic waveform from a wave-source to a wave-destination via the gel-like polymer or semi-liquid medium.

Device **150** also includes a haptic sensor or a controller, not shown in FIG. **1**(*a*), capable of determining physical location of an event, also known as the location of the interaction on touch surface **152**. The haptic sensor, in one embodiment, is capable of calculating a distance for every actuator between its location and the location of interaction. Upon detecting multiple interactions or events, the haptic sensor is configured to calculate distances between each actuator and the multiple locations of interactions. It should be noted that the haptic sensor or controller can be a part of touch surface **152**. Alternatively, the haptic sensor can be distributed across one or more actuators **156**. The calculated distances between actuators and location(s) are used by actuators **156** for generating haptic feedback as well as haptic phase actuation for canceling unwanted haptic responses. It should also be noted that the haptic sensor does not require the user to have direct contact with the touch surface before making its calculations for haptic responses.

Actuators **156**, in one embodiment, are physically located at the perimeter of touch surface **152**. It should be noted that depending on applications, additional actuators may be placed below or above touch surface **152**. Alternatively, actuators **156** can also be situated in one side, two sides, or three sides of the perimeter of touch surface **152**. Actuators **156**, in one embodiment, work in harmony or in synchrony to intensify the haptic feedback. A portion of haptic actuators **156** is allocated to provide haptic feedback to touch surface **152** in response to the event while another portion of haptic actuators **152** is used to minimize unwanted haptic effect on touch surface **152**. For example, while some actuators **156** located at the perimeter of touch surface **152** send haptic waves to an interactive point or location of the interaction, other actuators **156** emit actuations to cancel unwanted actuation waves.

To intensify haptic feedback at the interaction, various haptic waves generated by a group of actuators **156** arrive at the location of the interaction on touch surface **152** at the same time or substantially the same time. Since the distance between each actuator **156** and the location of interaction can be different, time to activate haptic wave for each actuator **156** is independent from its neighboring actuators thereby all of the haptic waves for generating haptic feedback can arrive at the same time. Similarly, to improve haptic feedback, various haptic actuations generated by another group of actuators **156** are used to cancel unwanted haptic waveforms, unwanted vibrations, or unwanted actuations across touch surface **152**. In one embodiment, actuators are also capable of generating haptic feedback to support multiple interactions in response to multiple touch events. It should be noted that actuators **156** may include one or more of the same or different types of haptic elements, such as fibers (or nanotubes) of electroactive polymers ("EAP"), piezoelectric elements, fiber of shape memory alloys ("SMAs"), plasma actuators, pneumatic actuators, electric actuators, motors, hydraulic cylinders, linear actuators, and the like.

Multi-actuated waveform phasing across the entire surface of touch surface **152** creates areas of greatest haptic actuation (s) at one or more touch points while canceling or reducing any perceived actuations in other areas of touch surface **152**. Touch surface **152** can be actuated through the use of a gel material having aquatic-like or paste-like medium by injecting energy into the medium in a controlled manner thereby various waveforms are produced. An advantage of using the haptic phase actuation for a multi-point touch system is that a user(s) can feel two distinctly different haptic responses in different areas of a touch surface without one response bleeding over into another response. For example, for a touch surface capable of simulating both texture and objects, when a user drags two fingers across the touch surface, he or she can feel a haptic texture with one finger and a haptic virtual button with another finger. It should be noted that haptic sensation (or response) at the location of the virtual button response is stronger than haptic sensation at the location of haptic texture.

When a point of contact on touch surface **152** is detected, haptic generators or actuators **156** react in combination to initiate haptic waveform pulses directly to the point of contact location with the intent of causing waveforms to collide, which renders haptic sensation at the point of contact(s). At the same time, other actuators **156** send canceling haptic pulses (waveforms) to eliminate or minimize any unwanted haptic responses or effects.

Actuators **156**, in one embodiment, are capable of providing kinesthetic feedback and/or tactile feedback, which are also known as haptic feedback. The kinesthetic feedback can be active and resistive force feedback while tactile feedback can be vibration, texture, and heat. Haptic feedback, for example, provides texture sensation in touch surface as well as cues that enhance and simplify user interface, such as virtual button interaction confirmations.

Device **150** is capable of generating haptic waves or pulses with varying frequencies, amplitudes, and durations, which allow different textures and/or haptic objects to be emulated. The texture(s) can be either across the whole touch surface or in a distinct area. In an alternative embodiment, a multi-point touch system provides multiple emulated textures simultaneously over different regions of touch surface **152**. For example, a user dragging two fingers across touch surface **152** may feel different textures on each finger. Furthermore, while simulated textures are being produced, device **150** can also provide virtual interfaces or objects, such as buttons, switches, or sliders. Virtual objects can be emulated by generating shorter and stronger confirming haptic responses initiated by haptic generators **156**.

In operation, a capacitive sensing circuit may be used to predetermine the intended location(s) of the touch interaction before a user touches touch surface **152**. The predetermination allows device **150** to identify which haptic actuator or generator(s) should be triggered with what amplitude and/or frequencies. The predetermination also provides an order to trigger generators **156** to increase haptic response at the touch point(s). In addition, some generators **156** are configured to provide phase actuation to eliminate or reduce unwanted haptic effect outside of the location(s). It should be noted that the underlying concept of the present invention does not change if other sensing technology, which provides similar sensing capabilities and/or functions as described-above, to predetermine the location(s) of the touch interactions.

FIG. **1**(*b*) is a perspective diagram **100** illustrating a haptic device capable of generating vibrotactile feedback using haptic phase actuation or multi-actuated waveform phasing in accordance with one embodiment of the present invention. Diagram **100** illustrates a touch sensitive panel or touch surface **110**, a display panel **104**, and a case **106**. Touch sensitive panel **110**, in one example, is made of substantially transparent material, and is capable of transmitting light whereby objects or images displayed in display **104** can be seen through touch sensitive panel **110**. Display **104** can be any type of display such as a cathode ray tube (CRT), liquid crystal display (LCD), plasma display, flat panel display, flexible display or the like. Both touch sensitive panel **110** and display **104** may be installed together with case **106** and/or integrated into the same unit or device. In some applications, display **104** may be removed from the haptic device when displaying images are not necessary. For example, a touch pad used on a laptop or on a vehicle dashboard, which does not require displaying images, can be opaque. It should be further noted that the underlying concept of the exemplary embodiment of the present invention would not change if one or more blocks (circuits or layers) were added to or removed from diagram **100**.

Touch sensitive panel **110** includes a touch surface **102** and a group of actuators or generator **124**. In one embodiment, panel **110** also includes an insulated layer or a protective layer, not shown in FIG. **1**(*b*), on top of panel **110** providing device protection. Actuators **124** form a ring of actuators physically situated around the four sides of the perimeter of touch surface **102**. Alternatively, actuators **124** can form a U-shaped formation connecting three sides of touch surface **102**. In another embodiment, actuators **124** can form an L-shaped configuration connecting two sides of touch surface **102**. Each haptic actuator or cell **124** is capable of providing a haptic effect in response to an input. When multiple contacts are depressed on touch surface **102** simultaneously, touch sensitive panel or touch panel **110** activates haptic actuators **124** to generate multiple haptic feedbacks in response to the multiple contacts. It should be noted that the multiple contacts may be made by one finger, multiple fingers, or pointed objects such as a stylus. The dimension or size of each of haptic areas can be configured to be less than 5 mm by 5 mm (millimeters), although other sizes can be used as appropriate. Touch panel **110** accepts a user's selection(s) when one or more touches are made or depressed by user's finger(s).

Touch panel **110** can also include other circuits together with actuators **124** mounted at the edge or otherwise attached to the panel via a cable or flexible circuit. Circuits may be used to provide digital control signals and/or a power source to actuators **124**. Case **106** can also include a digital processing unit for data, analog, and/or mixed signal processing. Haptic actuators **124** are configured to work in harmony to generate crisp vibrotactile or kinesthetic feedback through haptic phase actuation. It should be noted that the haptic actuators **124** do not necessarily cover the entire edge of touch surface **102**. The layout of haptic actuator **124** can be selectively configured to meet the requirements of a particular application.

Flexible surface layer **102**, in one instance, is made of soft and/or elastic materials such as silicone rubber, which is also known as polysiloxane. A function of the flexible surface layer **102** is to change its surface shape or texture to emulate a specific texture or objects such as buttons or barriers. It should be noted that the deformation of flexible surface layer **102** from one texture to another, for example, is controlled by the actuators **124**. For example, when actuators **124** are not activated, flexible surface layer **102** maintains its smooth configuration. The surface configuration of flexible surface layer **102**, however, deforms or changes from a smooth configuration to a coarse configuration when actuators **124** are activated.

Alternatively, flexible surface layer **102** is a flexible touch sensitive surface, which is capable of accepting user inputs. The flexible touch sensitive surface can be divided into multiple regions wherein each region of the flexible touch sensitive surface can accept an input when the region is being touched or depressed by a finger or a stylus. In one embodiment, the flexible touch sensitive surface includes a sensor, which is capable of detecting a nearby finger and waking up, or turning on, the device. Flexible surface layer **102** may also include a flexible display, which is capable of deforming together with flexible surface layer **102**. It should be noted that various flexible display technologies can be used to manufacture flexible displays, such as organic light-emitting diode (OLED), organic, or polymer TFT (Thin Film Transistor).

Haptic actuator **124** can also be referred to as a haptic mechanism, a haptic generator, a haptic layer, a tactile element, and the like, and are operable to provide haptic feedback in response to an activating command or signal. Actuators **124** provide multiple tactile or haptic feedbacks wherein one tactile feedback is used for surface deformation, while another tactile feedback is used for input confirmation. Input confirmation is a haptic feedback informing a user about a selected input. For example, actuators **124** can be implemented by various techniques including vibration, vertical displacement, lateral displacement, push/pull technique, air/fluid pockets, local deformation of materials, resonant mechanical elements, piezoelectric materials, micro-electro-mechanical systems ("MEMS") elements, thermal fluid pockets, MEMS pumps, variable porosity membranes, laminar flow modulation, or the like.

Haptic actuators **124**, in one embodiment, can be constructed by flexible, semi-flexible, semi-rigid, or rigid materials. For example, actuators **124** may be constructed with fibers (or nanotubes) of EAP, piezoelectric elements, fiber of SMAs or the like. EAP, also known as biological muscles or artificial muscles, is capable of changing its shape in response to an application of voltage. The physical shape of an EAP may be deformed when it sustains large force. EAP may be constructed with electrostrictive polymers, dielectric elastomers, conducting polymers, ionic polymer metal composites, responsive gels, bucky gel actuators, or a combination of the above-mentioned EAP materials.

SMA, also known as memory metal, is another type of material which can be used to construct haptic actuator **124**. SMA may be made of copper-zinc-aluminum, copper-aluminum-nickel, nickel-titanium alloys, or a combination of copper-zinc-aluminum, copper-aluminum-nickel, and/or nickel-titanium alloys. A characteristic of SMA is that when its original shape is deformed, it regains its original shape in accordance with the ambient temperature and/or surrounding environment. It should be noted that the present embodiment may combine the EAP, piezoelectric elements, and/or SMA to achieve a specific haptic sensation.

Upon receipt of a first activating signal, a sensor or controller calculates a distance for every actuator indicating a waveform traveling distance between a touch point (or an interaction location) and an actuator. Some actuators are activated to intensify haptic feedback at the touch spot while other actuators are activated to minimize unwanted actuations across touch surface **102**. If multiple touch spots are determined, a more sophisticated computation is required to determine waveform travel distances for every actuator **124** thereby multiple haptic feedbacks can be generated.

FIG. **2**(*a*) illustrate a haptic device **200** capable of generating haptic feedback using multi-actuated waveform phasing across a touch surface in accordance with one embodiment of the present invention. Device **200** includes a touch surface **202** and a group of actuators **206** capable of providing haptic phase actuation. Actuators **206** are coupled to the perimeter of touch surface **202**. Touch surface **202** is also known as a touch pad, a haptic layer, a touch sensitive surface, a flexible touch sensitive surface, or the like. It should be further noted that the underlying concept of the exemplary embodiment of the present invention would not change if one or more blocks (circuits or layers) were added to or removed from device **200**.

Device **200** is activated when it detects a contact or a touch by a finger **218**. Upon determining a location **208** of the touch point, distances **220-226** between actuators **210-216** and location **208** are subsequently calculated. It should be noted that distances **220-226** are different dimensions since the physical distance for an actuator such as actuator **210** is different from other actuator such as actuator **212**. After identifying distances **220-226**, actuators **210-216** are activated in an order in accordance with distances **220-226** whereby the pulse movements or waveforms generated by actuators **210-216** arrive at location **208** at the same time. When the pulse movements collide and strike at location **208**, the haptic feedback at location **208** is intensified. It should be noted that haptic actuators or generators **210-216** react in combination or in harmony for sending haptic waveform pulses directly to location **208** with the intent of causing the waveforms to collide whereby causing an intensified haptic response at the touch interaction point(s). It should be further noted that additional actuators may be used to intensify the vibrotactile response(s). Alternatively, depending on the applications, some actuators **206** may not be necessary and can be removed from device **200**.

FIG. **2**(*b*) illustrate a haptic device **250** capable of reducing unwanted haptic effect using multi-actuated waveform phasing across a touch surface in accordance with one embodiment of the present invention. Device **250** includes a touch surface **252** and a group of actuators **206** capable of providing haptic phase actuation. Actuators **206** are coupled to the perimeter of touch surface **252**. It should be further noted that the underlying concept of the exemplary embodiment of the present invention would not change if one or more blocks (circuits or layers) were added to or removed from device **250**.

Device **250** is activated when it detects a contact or touch by an object or a finger. Upon determining a location **258** of the touch point, distances **270-276** between actuators **260-266** and location **258** are calculated. It should be noted that distances **270-276** are different in length since the physical distance for an actuator such as actuator **260** is different from the distance for a neighboring actuator such as actuator **262**. After identifying distances **270-276**, actuators **260-266** are activated in accordance with distances **270-276** whereby the pulse movements or waveforms generated by actuators **260-266** cancel or minimize any unwanted waveforms outside of touch point **258**. When unwanted waveforms are reduced, the haptic feedback at location **208** is increased. Depending on the applications, some actuators **206** may not be needed for reducing unwanted waveforms, and consequently, can be removed from device **200**.

Device **200** or **250** can employ various types of haptic generators, haptic actuators, or a combination of different types of haptic actuators to emulate object sensations, texture sensations, haptic fabric, haptic feedback acknowledgements, or the like. It should be noted that haptic substrates, haptic actuators, and/or haptic mechanisms as described above are used to control haptic feedback for haptic device. A combination of different haptic actuators, generators, and/or haptic mechanisms can be used in a haptic device to achieve the best haptic results. The following embodiments of actuators illustrated in FIG. **3** through FIG. **8** are exemplary actuators, which can be employed to provide haptic sensation or feedback using haptic phase actuation.

FIG. **3** illustrates an example of actuator **300** capable of generating crisp haptic effects using a relay actuator in accordance with exemplary embodiment(s) of the present invention. Actuator **300** includes two L-shaped pole pieces **310-312**, first and second structural elements **302-304**, and first and second biasing elements **306-308**. Pole pieces **310-312** may be made of standard magnetic steels with high permeability or other suitable ferromagnetic materials such as soft magnetic materials with high magnetic permeability (e.g., iron, nickel, magnetic alloys). Pole pieces **310-312** need not be made of the same material and they are further coupled to coils **314***a*, **314***b* to form electromagnetic devices ("magnetic device"). In another embodiment, one of the pole pieces need not include a coil as long as it is fabricated with ferromagnetic material.

Actuator **300** includes structural elements **302**, **304** and first and second biasing elements **306**, **308** to form a frame for the actuator **300**. First structural element **302**, as shown in FIG. **3**, includes apertures **320-322**, which are coupled or fastened to housing, a display or a touch sensitive panel. Similarly, structural element **304** also contains apertures **324**, **326** for similar coupling. Biasing elements **306**, **308**, which may be springs, flexure springs, flexible blades, flexible members, elastomeric components, foam components, and the like, are made of elastic or relatively flexible materials that can be compressed and/or stretched within a predefined range

Referring again to FIG. **3**, pole pieces **310** and **312** are coupled to structural elements **302** and **304**, respectively. Pole piece **310** is placed adjacent to pole piece **312** with three magnetic gaps **340**, **342** and **344** between the pole pieces **310**, **312**. The width of gaps **340**, **342** is in one embodiment, in a range of about 0.25 to about 0.75 mm. Air pockets **330**, **332**, which can be of any shape, provide space for pole pieces **310**, **312** to move. Because gaps **340**, **342** are much smaller than gap **344**, the attractive magnetic force at gaps **340**, **342** dominates over any attractive force across gap **344**.

In operation, biasing elements **306**, **308** provide minimal force if there is no current passing through coils **314** and the actuator is (accordingly) in a relaxed state. Under this no power condition, the actuator attains a first equilibrium position as shown, for example, in FIG. **3**. When power is applied to coil(s) **314***a*-**314***b*, an input current passes through the coil(s) creating magnetic flux lines **350** in pole pieces **310-312** and across gaps **340-342**. This process generates an attractive force or attractive magnetic force between pole pieces **310-312** when the coils are wound so that the electromagnetic effects do not cancel one another. The term attractive force and attractive magnetic force are used interchangeably herein. The attractive magnetic force acts against biasing elements **306-308** and pulls pole pieces **310-312** closer together at gaps **340-342**. In accordance with the embodiment shown in FIG. **3**, under the attractive magnetic force, with structural element **302** held fixed, pole piece **312** moves in a direction from right to left (as indicated by arrow **338**) toward pole piece **310**. Pole piece **310**, in this embodiment, may be fastened or secured to structural element **302**, which may be further secured to a housing, touch sensitive panel or display device. When one of pole pieces **310-312** is displaced enough distance within gaps **340-342**, a second equilibrium position is reached as increasing spring force is applied in an opposite direction by biasing elements **306-308**. When power is then reduced or removed, the biasing elements **306-308** force pole pieces **310-312** back to their original no-power position, also known as the first equilibrium position as described earlier.

FIG. **4**(*a*) illustrates a tactile or haptic region **410** using piezoelectric materials to generate haptic effects in accordance with one embodiment of the present invention. Region **410** includes an electrical insulated layer **402**, a piezoelectric material **404**, and wires **406**. Electrical insulated layer **402** has a top surface and a bottom surface, wherein the top surface is configured to receive inputs. A grid or an array of piezoelectric materials **404** in one embodiment is constructed to form a piezoelectric or haptic layer, which also has a top and a bottom surface. The top surface of the piezoelectric layer is situated adjacent to the bottom surface of electrical insulated layer **402**. Each region **410** includes at least one piezoelectric material **404** wherein piezoelectric material **404** is used to generate haptic effects independent of other piezoelectric region **410** in piezoelectric layer. In one embodiment, multiple adjacent or neighboring regions **410** are capable of generating multiple haptic effects in response to multiple substantially simultaneous touches. In another embodiment, each of regions **410** has a unique piezoelectric material thereby it is capable of initiating a unique haptic sensation.

It should be noted that a tactile touch panel, which includes an electrical insulated layer **402** and a piezoelectric layer, in some embodiments further includes a display, not shown in the figure. This display may be coupled to the bottom surface of the piezoelectric layer and is capable of projecting images that are viewable from the top surface of electrical insulated layer **402**. It should be noted that the display can be a flat panel display or a flexible display. Piezoelectric materials **404**, in one embodiment, are substantially transparent and small. The shape of piezoelectric material **404**, for example, deforms in response to electrical potentials applied via electrical wires **406**.

During a manufacturing process, a piezoelectric film is printed to include an array or a grid of piezoelectric regions **410**. In one embodiment, a film of regions **410** containing piezoelectric materials is printed on a sheet in a cell grid arrangement. The film further includes wirings for directly addressing every region **410** in the device using electrical control signals. Region **410**, for example, can be stimulated using edge or back mounted electronics. Piezoelectric materials may include crystals and/or ceramics such as quartz (SiO_2).

FIG. **4**(*b*) illustrates a tactile or haptic region **410** generating haptic effects in accordance with an embodiment of the present invention. During operation, when a voltage potential applies to piezoelectric material **405** via wires **406**, piezoelectric material **405** deforms from its original shape of piezoelectric material **404**, as shown in FIG. **4**(*a*), to an expanded shape of piezoelectric material **405**. Deformation of piezoelectric material **405** causes electrical insulated layer **403** to deform or strain from its original state of layer **402**, as shown in FIG. **4**(*a*). In an alternative embodiment, piezoelectric materials **405** return to its original state as soon as the voltage potential is removed. It should be noted that the underlying concept of the present invention does not change if additional blocks (circuits or mechanical devices) are added to the device illustrated in FIG. **4**(*a-b*). If the piezoelectric material is replaced with other materials such as SMAs, such material may be capable of maintaining its deformed shape for a period of time after the voltage potential is removed. It should be noted that the underlying concept of the embodiments of the present invention does not change if different materials other than piezoelectric actuators are employed. As such a grid of piezoelectric actuators may be used to control the surface texture of touch sensitive surface of the interface device.

FIG. **4**(*c*) is a diagram **450** illustrating another embodiment of a tactile or haptic region or cell **410** using MEMS device **452** to generate haptic effects in accordance with one embodiment of the present invention. Diagram **450** depicts a block **460**, which shows a top view of cell **410**. Cell **410** includes a MEMS device **452**. In one embodiment, MEMS device **452** is substantially transparent thereby the image projection from a display, not shown in FIG. **4**(*c*), can be viewed through block **460**. It should be noted that each of haptic cells **410** is coupled to at least one wire to facilitate and generate haptic effects.

MEMS can be considered as an integration of mechanical devices, sensors, and electronics on a silicon or organic semiconductor substrate, which can be manufactured through conventional microfabrication process. For example, the electronic devices may be manufactured using semiconductor fabrication process and micromechanical devices may be fabricated using compatible microfabrication process. In one embodiment, a grid or an array of MEMS devices **452** are made of multiple cantilever-springs. A grid of cantilever-springs can be etched using MEMS manufacturing techniques. Also, electrical wirings for stimulating or driving cantilever-springs can also be directly etched onto the surface of the MEMS device **452** thereby every single MEMS device can be correctly addressed. MEMS cantilevers can be stimulated using a resonant drive (for vibrotactile) or direct actuation (kinesthetic).

FIG. **4**(*d*) illustrates a side view of MEMS device **452**, wherein MEMS device **462** can be stimulated or deformed from its original state of MEMS device **452** to deformed state of MEMS device **464** when a voltage potential across MEMS device is applied. Displacement **454** between the original state and the deformed state depends on the composition of materials used and the size of MEMS device **452**. Although smaller MEMS devices **452** are easier to fabricate, they offer smaller displacement **454**. In one embodiment, cantilever-springs can be made of piezo materials. It should be noted that the actuation of piezo material is generally vibrotactile sensation. It should be further noted that piezo material can be used as a sensor for sensing fingertip positions and depressions.

MEMS device **452**, in another embodiment, uses SMA in place of cantilever-spring as mentioned above. The actuation generated by MEMS device **452** using SMA provides kinesthetic actuation. SMA, also known as memory metal, could be made of copper-zinc-aluminum, copper-aluminum-nickel, nickel-titanium alloys, or a combination of copper-zinc-aluminum, copper-aluminum-nickel, and/or nickel-titanium alloys. Upon deforming from SMA's original shape, SMA regains its original shape in accordance with an ambient temperature and/or surrounding environment. It should be noted that the present invention may combine piezoelectric elements, cantilever-spring, and/or SMA to achieve a specific haptic sensation. As such, a grid of MEMS device **452** may be used to control the surface texture of touch sensitive surface of the interface device.

FIG. **5**(*a*) is a side view diagram of an interface device **500** illustrating an array of haptic cells or tactile region **502** with thermal fluid pockets **504** in accordance with one embodiment of the present invention. Device **500** includes an insulated layer **506**, a haptic layer **512**, and a display **508**. While the top surface of insulated layer **506** is capable of receiving inputs from a user, the bottom surface of insulated layer **506** is placed adjacent to the top surface of haptic layer **512**. The bottom surface of haptic layer **512** is placed adjacent to display **508**, wherein haptic layer **512** and insulated layer **506** may be substantially transparent thereby objects or images displayed in display **508** can be seen through haptic layer **512** and insulated layer **506**. It should be noted that display **508** is not a necessary component in order for the interface device to function.

Haptic layer **512**, in one embodiment, includes a grid of fluid filled cells **502**, which further includes at least one thermal fluid pocket **504** and an associated activating cell **510**. It should be noted that each of fluid filled cells **502** can include multiple thermal fluid pockets **504** and associated activating cells **510**. In another embodiment, a fluid filled cell **502** includes multiple associated or shared activating cells **510** thereby initiating a different activating cell generates a different haptic sensation(s).

Activating cell **510**, in one embodiment, is a heater, which is capable of heating an associated thermal fluid pocket **504**. Various electrical, optical, and mechanical techniques relating to heating technology can be used to fabricate activating cells **510**. For example, various electrically controlled resistors can be used for activating cells **510**, wherein resistors can be implanted in haptic layer **512** during the fabrication. Alternatively, optical stimulators such as infrared lasers can be used as activating cells **510** to heat up thermal fluid pockets **504**. Optical stimulator, for example, can be mounted at the edge of the interface device. It should be noted that activating cells **510** can be any types of optical or radioactive stimulator as long as it can perform the function of a heating device. Activating cells **510** may also include rear mounted thermal stimulators, which are similar technologies like hot plasma displays such as are commonly found in flat panel plasma televisions.

Device **500** further includes a set of control wires, not shown in FIG. **5**(*a*), wherein each of activating cells **510** is coupled to at least one pair of wires. The wires are configured to transmit activating/deactivating control signals, which are used to drive activating cells **510**. It should be noted that each of fluid filled cells **502** is addressable using signals from wires or wireless networks. Display **508**, in one aspect, can be a flat panel display or a flexible display. In an alternative embodiment, the physical location of display **508** is exchangeable with haptic layer **512**. Also, thermal fluid pockets **504**, in one embodiment, can be activated by a piezoelectric grid.

Thermal fluid pockets **504**, in one embodiment, include fluid with physical properties of low specific heat and high thermal expansion. Examples of this fluid include glycerin, ethyl alcohol, or the like. Thermal fluid pockets **504** are capable of producing multiple localized strains in response to multiple touches received by insulated layer **506**. Each localized strain is created by a heated thermal fluid pocket **504** wherein the heat is generated by an associated activating cell **510**. In one embodiment, a thermal fluid pocket **504** changes its physical shape in accordance with the temperature of the fluid in the pocket. In another embodiment, fluid filled cell **502** has an active cooling system, which is used to restore the expanded shape of thermal fluid pocket **504** to its original shape after it is deactivated. The control of fluid temperature affects haptic bandwidth. Rapid rising of fluid temperature and fast heat dissipation of fluid enhance haptic bandwidth of thermal fluid packets.

The physical size of each fluid cell **502** can also affect the performance of the cell for generating haptic sensation(s). For example, if the size of fluid cell **504** is smaller than ½ fingertip, the performance of cell **504** enhances because smaller cell permits rapid heat dissipation as well as quick temperature rising of fluid in the cell. In another embodiment, thermal plastic pockets filled with plastic fluid are used in place of thermal fluid pockets **504** filled with thermally sensitive fluid to enhance the haptic effects. Using thermal plastic pockets filled with plastic-like fluid can produce high thermal plastic strain. For example, a type of plastic fluid is polyethylene. Thermal plastic pockets can also provide different and unique haptic sensations to the user. In another embodiment, some exotic fluids such as electrorheological and/or magnetorheological fluid can be used in place of thermal fluid in thermal fluid pockets **504**. Thermal fluid pockets **504** filled with electrorheological fluid can be stimulated by a local or remote electrical field, while thermal fluid pockets **504** filled with magnetorheological fluid can be stimulated by a local or remote magnetic field.

FIG. **5**(*b*) is a side view diagram for an interface device **550** illustrating an array of haptic cells **502** using thermal fluid pockets **554** in accordance with one embodiment of the present invention. Device **550** also shows an activated thermal fluid pocket **554** and an activated activating cell **560**. During the operation, thermal fluid pocket **554** increases its physical volume (or size) from its original state **556** to expanded thermal fluid pocket **554** when activating cell **560** is activated. When activating cell **560** is activated, it provides heat **562** to thermal fluid pocket **554** or **556** to expand the size of thermal fluid pocket **554** or **556**. Due to the expansion of thermal fluid pocket **554**, a localized portion **552** of insulated layer **506** is created. As soon as the temperature of the fluid in the thermal fluid pocket **554** cools down, the size of thermal fluid pocket **554** returns to its original state **556**. The change of size between original size of a thermal fluid pocket **556** and expanded size of thermal fluid pocket **554** generates a haptic effect. It should be noted that activating cell **560** could be an electric heater or an optical heater such as an infrared simulator. As such, an array of haptic cells using thermal fluid pockets **552** may be used to control the surface texture of touch sensitive surface of the interface device.

FIG. **6**(*a*) is a side view diagram of an interface device **600** illustrating an array of MEMS pumps **602** in accordance with one embodiment of the present invention. The array of MEMS pumps **602** can be used to implement tactile regions for controlling surface textures. Diagram **600** includes an insulated layer **606** and a haptic layer **612**. While the top surface of insulated layer **606** is configured to receive a touch or touches from a user, the bottom surface of insulated layer **606** is placed adjacent to the top surface of haptic layer **612**. The bottom surface of haptic layer **612** is, in one embodiment, placed adjacent to a display (not shown in FIG. **6**(*a*)), wherein haptic layer **612** and insulated layer **606** may be substantially transparent thereby objects or images displayed in the display can be seen through haptic layer **612** and insulated layer **606**. It should be noted that display is not a necessary component in order for the interface device to function.

Haptic layer **612**, in one embodiment, includes a grid of MEMS pumps **602**, which further includes at least one pocket **604**. Each MEMS pump **602** includes a pressurized valve **608** and a depressurized valve **610**. Pressurized valve **608** is coupled to an inlet tube **614** while depressurized valve **610** is coupled to an outlet tube **616**. In one embodiment, inlet tube **614**, which is under high liquid pressure, is used to pump liquid through pressurized valve **608** to expand pocket **604**. Similarly, outlet tube **616**, which is under low pressure, is used to release the liquid through depressurized valve **610** to release the pressure from pocket **604**. In one embodiment, MEMS pumps **602** can be coupled to the same pressurized liquid reservoir. In addition, pressurized valve **608** and depressurized valve **610** may be combined into one single valve for both inlet tube **614** and outlet tube **616**. It should be noted that inlet tube **614** and outlet tube **616** can also be combined into one tube.

A grid of MEMS pumps **602** includes an array of pressurized valves **608** and depressurized valves **610**, wherein pressurized valves **608** are coupled with a rear or a side mounted liquid reservoir under pressure while depressurized valves **610** are coupled to a rear or a side mounted depressurized liquid reservoir with low pressure. Valves **608-610** control the filling and emptying the liquid pockets **604** in MEMS pumps **602** to produce localized strain. An advantage of using pressurized liquid reservoir is to quickly deform the surface of insulated layer **606** and to maintain the deformation with minimal or no energy consumption (or expenditure). It should be noted that MEMS pump **602** can also use pressurized air or other gases to achieve similar results as liquid.

Device **600** further includes a set of control wires **617-618**, which can be used to control pressurized valve **608** and depressurized valve **610**, respectively. It should be noted that each valve in haptic layer **612** is addressable using electrical signals transmitted from wires or wireless network.

FIG. **6**(*b*) illustrates two diagrams of an interface device **620** and **650** having an array of MEMS pumps **604** in accordance with one embodiment of the present invention. Device **620** illustrates an activated pocket **623**, which includes an activated inlet valve **630** and a deactivated outlet valve **632**. During an operation, pocket **623** increases its physical volume (or size) from its original state **624** to its expanded pocket **623** when inlet valve **630** is activated. When inlet valve **630** is activated (or open) in response to electrical signal from wire **628**, inlet tube **625** pumps liquid **626** from pressurized reservoir to pocket **623**. Due to the expansion of pocket **623**, a localized strain **622** of insulated layer **606** is created.

Device **650** illustrates an activated MEMS pump returns from its expanded state of pocket **623** to the original state of pocket **653**. When depressurized valve **660** is activated, depressurized valve **660** releases liquid **656** from pocket **653** to low pressurized outlet **654**. It should be noted that depressurized valve **660** is controlled by at least one control signal via wire **658**. The change in volume between original size of pocket **604** and expanded size of pocket **623** generates haptic effects. As such, an array of MEMS pumps **602** may be used to control the surface texture of touch sensitive surface of the interface device.

FIG. **7** illustrates a side view diagram for an interface device **700** having an array of haptic cells **702** using variable porosity membrane **710** in accordance with one embodiment of the present invention. The porosity membrane **710** can be used to implement tactile regions for controlling surface textures. Device **700** includes an insulated layer **706** and a haptic layer **712**. While the top surface of insulated layer **706** is configured to receive inputs from a user, the bottom surface of insulated layer **706** is placed adjacent to the top surface of haptic layer **712**. The bottom surface of haptic layer **712** is, in one embodiment, placed adjacent to a display (not shown in FIG. **7**), wherein haptic layer **712** and insulated layer **706** may be substantially transparent thereby objects or images displayed in the display can be seen through haptic layer **712** and insulated layer **706**. It should be noted that display is not a necessary component in order for the interface device to function.

Haptic layer **712**, in one embodiment, includes a grid of haptic cells **702**, inlet valves **703**, and outlet valves **704**. Haptic cells **702**, in one embodiment, are pockets capable of containing fluid. Haptic layer **712** is similar to haptic layer **612** as shown in FIG. **6**(*a*) except that haptic layer **712** employs porosity membranes. While each inlet valve **703** is controlled by control signal(s) transmitted by wire **713**, each outlet valve **704** is controlled by electrical signals transmitted over a wire **714**. Every inlet valve **703** or outlet valve **704** employs at least one porosity membrane **710**. Porosity membranes **710** are coupled (or faced) to a liquid reservoir wherein each membrane **710** is configured to control how much liquid should enter and/or pass through membrane **710**. An advantage of using porosity membranes is to maintain the deformation of insulated layer **706** with minimal or no energy consumption. As such, a grid of haptic cells using variable porosity membrane **710** may be used to control the surface texture of touch sensitive surface of the interface device.

FIG. **8** is a side view of an interface device **800** having an array of haptic cells **802** using various resonant devices in accordance with one embodiment of the present invention. The array of haptic cells **802** can be used to implement tactile regions for controlling surface textures. Device **800** includes an insulated layer **806** and a haptic layer **812**. While the top surface of insulated layer **806** is configured to receive an input from a user, the bottom surface of insulated layer **806** is placed adjacent to the top surface of haptic layer **812**. The bottom surface of haptic layer **812** is, in one embodiment, placed adjacent to a display (not shown in FIG. **8**), wherein haptic layer **812** and insulated layer **806** may be substantially transparent thereby objects or images displayed in the display can be seen through haptic layer **812** and insulated layer **806**. It should be noted that insulated layer **806** may be flexible whereby it is capable of providing desirable relief information on its surface.

Haptic layer **812**, in one embodiment, includes a grid of haptic cells **802**, wherein each cell **802** further includes a permanent magnet **804**, an electro magnet **810**, and two springs **808**. Haptic layer **812** is similar to haptic layer **612** shown in FIG. **6**(*a*) except that haptic layer **812** employs resonant devices while haptic layer **612** uses MEMS pumps. Haptic cell **802**, in one embodiment, uses a resonant mechanical retractable device to generate haptic effects. The resonant mechanical retractable device vibrates in response to a unique frequency, which could be generated by a side mounted resonant stimulator **816** or a rear mounted resonant stimulator **814**. A resonant grid, in one embodiment, is used to form a haptic layer **812**. Each cell **802** is constructed using resonant mechanical elements such as linear resonant actuator or MEMS springs. Each cell **802**, however, is configured to have a slightly different resonant frequency and a high Q (high amplification at resonance and a narrow resonant frequency band). As such, each cell **802** can be stimulated using mechanical pressure waves originating at the edges of the sheet. The haptic effects can also be generated by a piezoelectric or other high bandwidth actuator.

Cell **802**, in another embodiment, includes one spring **808**. In yet another embodiment, cell **802** includes more than two springs **808**. Each spring **808** is configured to respond to a specific range of frequencies thereby each spring **808** can produce a unique haptic sensation. As such, a grid of haptic cells using various resonant devices may be used to control the surface texture of touch sensitive surface of the interface device. For example, if the displacement of haptic mechanism is sufficiently high such as 200 micrometers or greater, the movement (or tactile vibration) with low frequencies such as 50 Hz or less should sufficiently create desirable relief information.

The exemplary embodiment(s) of the present invention includes various processing steps which will be described below. The steps of the embodiments may be embodied in machine or computer executable instructions. The instructions can be used to cause a general purpose or special purpose system or controller, which is programmed with the instructions, to perform the steps of the embodiment(s) of the present invention.

FIG. **9** is a flowchart **900** illustrating a process of generating haptic feedback using multi-actuated waveform phasing in accordance with one embodiment of the present invention. At block **902**, the process monitors a flexible surface or touch surface in accordance with a set of predefined parameters or events. For example, the process is capable of sensing a contact, movement, predefined temperature, light, and/or a predefined audible sound.

At block **904**, the process detects an interaction on the flexible surface in response to an event. For example, the process is able to sense or detect a depression by a pointed object on the flexible surface. It should be noted that the pointed object can be a finger, a stylus, a pen, or the like.

At block **906**, the process is capable of determining a location of the contact on the flexible surface in response to the interaction. In one embodiment, the process is capable of identifying physical coordinates of a contact point with respect to the flexible or touch surface. For example, the process translates the location of contact point into a two-dimensional coordinating system such as x-axis and y-axis.

At block **908**, the process is able to calculate a first distance from a first haptic actuator to the location and a second distance from a second haptic actuator to the location. It should be noted that some distances are used for generating haptic feedback while other distances are utilized for reducing unwanted haptic effect.

At block **910**, the process activates the first haptic actuator in response to the first distance and the second haptic actuator in response to the second distance to generate haptic feedback at the location of the interaction. A haptic wave capable of traveling via a medium of a flexible surface is initiated to generate haptic feedback at the first location when the haptic wave reaches the location. In one aspect, upon calculating a third distance from a third haptic actuator to the location and a fourth distance from a fourth haptic actuator to the location, a third haptic actuator is activated in response to the third distance and a fourth haptic actuator is activated in response to the fourth distance. Note that the third and fourth actuators are used to cancel or reduce any unwanted haptic effect on the flexible surface. In another aspect, upon detecting a second interaction on the flexible surface, the process determines a second location of the second interaction on the flexible surface in response to the second interaction. After calculating a fifth distance from a fifth haptic actuator to the second location and a sixth distance from a sixth haptic actuator to the second location, the process activates the fifth haptic actuator in response to the fifth distance and the sixth haptic actuator in response to the sixth distance for providing haptic feedback at the second location. In another embodiment, after calculating a seventh distance from a seventh haptic actuator to the second location of the second interaction, the process is able to activate the seventh haptic actuator in response to the seventh distance for minimizing unwanted haptic effect on the flexible surface.

While particular embodiments of the present invention have been shown and described, it will be obvious to those skilled in the art that, based upon the teachings herein, changes and modifications may be made without departing from this invention and its broader aspects. Therefore, the appended claims are intended to encompass within their scope of all such changes and modifications as are within the true spirit and scope of the exemplary embodiment(s) of the present invention.

What is claimed is:

1. A haptic device, comprising:

a touch surface configured to sense a first event;

a first plurality of haptic actuators coupled to the touch surface, each of the first plurality of haptic actuators configured to generate at least one haptic waveform pulse to provide haptic feedback to the touch surface in response to the first event; and

a second plurality of haptic actuators coupled to the touch surface, each of the second plurality of haptic actuators configured to generate at least one canceling haptic waveform pulse to minimize unwanted haptic effects on the touch surface in accordance with the first event.

2. The device of claim **1**, further comprising a haptic sensor coupled to the touch surface and configured to sense the first event, wherein the haptic sensor calculates a distance between at least one of the haptic actuators and a location of the first event.

3. The device of claim 1, wherein the touch surface is a flexible touch sensitive surface, wherein the flexible touch sensitive surface is made of gel materials.

4. The device of claim 1, wherein the touch surface is a flexible wave transmittable touch pad.

5. The device of claim 1, wherein the first event includes a depression on the touch surface by a finger.

6. The device of claim 1, wherein the first event includes a depression on the touch surface by a stylus.

7. The device of claim 1, wherein the first plurality of haptic actuators are coupled to perimeter of the touch surface and configured to generate and send haptic waves to an interactive point.

8. The device of claim 1, wherein the first plurality of haptic actuators are configured to generate and send multiple haptic waveform pulses to an interactive point, wherein the haptic waveform pulses arrive at the interactive point at substantially same time.

9. The device of claim 1, wherein the second plurality of haptic actuators are configured to generate and send multiple canceling haptic waveform pulses to cancel various unwanted haptic waveform pulses on the touch surface.

10. The device of claim 1,

wherein the touch surface is further configured to sense a second event; and

wherein the first plurality of haptic actuators are configured to generate haptic feedback to the touch surface in response to the second event.

11. The device of claim 1, wherein the first and second plurality of actuators include one or more types of haptic elements.

12. A method of providing haptic feedback, comprising:

detecting a first interaction on a flexible surface;

determining a first location on the flexible surface in response to the first interaction;

calculating a first distance from a first haptic actuator to the first location and a second distance from a second haptic actuator to the first location; and

activating the first haptic actuator to generate a first haptic waveform pulse in response to the first distance and the second haptic actuator to generate a second haptic waveform pulse in response to the second distance to generate haptic feedback at the first location.

13. The method of claim 12, further comprising:

monitoring a flexible surface; and

calculating a third distance from a third haptic actuator to the first location and a fourth distance from a fourth haptic actuator to the first location.

14. The method of claim 13, further comprising activating the third haptic actuator in response to the third distance and the fourth haptic actuator in response to the fourth distance to cancel unwanted haptic effect on the flexible surface.

15. The method claim 12, further comprising:

detecting a second interaction on the flexible surface;

determining a second location on the flexible surface in response to the second interaction;

calculating a fifth distance from a fifth haptic actuator to the second location and a sixth distance from a sixth haptic actuator to the second location; and

activating the fifth haptic actuator in response to the fifth distance and the sixth haptic actuator in response to the sixth distance to generate haptic feedback at the second location.

16. The method of claim 15, further comprising:

calculating a seventh distance from a seventh haptic actuator to the second location; and

activating the seventh haptic actuator in response to the seventh distance to minimize unwanted haptic effect on the flexible surface.

17. The method of claim 13, wherein monitoring a flexible surface includes sensing one of a contact, a movement, a predefined temperature, a light, and a predefined audible sound.

18. The method of claim 12, wherein detecting a first interaction on the flexible surface includes sensing a depression by a pointed object on the flexible surface.

19. The method of claim 12, wherein determining a first location on the flexible surface includes identifying physical coordinates of a contact point with respect to the flexible surface.

20. The method of claim 12, wherein activating the first haptic actuator in response to the first distance further includes generating a haptic wave traveling through medium of the flexible surface to generate haptic feedback at the first location.

21. A method of providing haptic feedback, comprising:

detecting a first interaction at a first location on a flexible surface;

generating a plurality of haptic waveform pulses with a first plurality of actuators to provide haptic feedback to the first location on the flexible surface in response to the detecting; and

generating a plurality of canceling haptic waveform pulses with a second plurality of actuators to minimize unwanted haptic effects on the flexible surface at locations other than the first location.

22. The method of claim 21, further comprising

calculating a first distance from at least one of the first plurality of haptic actuators to the first location prior to said generating the plurality of haptic waveform pulses to determine which of the first plurality of actuators to actuate; and

calculating a second distance from at least one of the second plurality of haptic actuators to the first location prior to said generating the plurality of canceling haptic waveform pulses to determine which of the second plurality of actuators to actuate.

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